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PREFACE

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The arrangement which has been adopted will, it is also hoped, be found satisfactory. In the more substantial parts of the general articles had alone been regarded, we should in many cases have had the application of principles described before the principles themselves had been illustrated, which would have been a more convenient and all the advantages derivable from it would have been lost. It would have been attended with too great a liability to any particular article. The want of any comprehensive knowledge supplied by the author, and the necessity of having the author at liberty to place the articles in their natural order of dependence on each other.

The first section treats of the different forces employed to give motion to Machinery, as a human strength, the power of horses, wind, water, and steam; secondly, of the forces which retard the motion, as friction, rigidity, resistance, &c.

The elementary parts of mill-work and their construction are then described, with different methods of conveying and discharging Machinery—modes of equalizing the motion, and converting motion from one species to another; the theory of the fly-wheel, &c.

The principles of mill-work being thus separately illustrated, we next describe the construction of mills, but simply with reference to the power which puts them in motion, without regard to the work they are intended to perform; that and the nature of the work is then divided into hand-mills, tread-mills, horse and water-mills, wind-mills, and steam-mills. The steam-engine, according to the state of the subject, becomes also a mill of a like class, but from its importance it is made to form the subject of a distinct section. Here we examine first the elastic power, and other properties of steam, and finally the nature of the several contrivances for the production of steam.

P R E F A C E.

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CONTENTS TO VOL. VIII.

	PAGE
PREFACE	V.
INTRODUCTORY VIEW OF THE PRINCIPLES OF MANUFACTURES. By CHARLES BABBAGE, Esq., F.R.S., &c.	1
MANUFACTURES. By PETER BARLOW, Esq., F.R.S., &c.	85

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to mechanical purposes, that is, of the invention of the steam-engine. Next is described the several parts of the modern steam-engine under its different forms, and their combination in the single and double-acting engine, high-pressure engine, vibrating engine, &c.; and, lastly, their comparative effect, and the method of estimating their power.

In the following Section is illustrated the application of steam power to Mining, to Navigation, to locomotive engines on railways and common roads. In the course of these articles is shown the method of working copper-mines, tin-mines, iron-mines, coal-mines, &c., with the product of each kind in Great Britain for several successive years. The extraordinary progress of steam navigation also is exhibited, and the probable extent and great mercantile advantages likely to be derived from the establishment of railways.

The next division treats of such machines as admit of description without an immediate reference to the mechanical processes they are intended to effect; and these, conforming rather to general use than to any intrinsic difference, are divided into engines and machines, and the former into different classes, as cutting engines, hydraulic engines, fire-engines, &c.; but the machines being of various kinds, not easily separated into classes, are treated of under one head, and are arranged alphabetically.

Having thus illustrated the elementary principles of practical mechanics, and shown the combination of the several parts in the production of different engines and machines, we pass to their application to various purposes. In a preceding chapter is described the construction of mills, with reference only to the agent by which they were put in motion; and in this place we treat of their application to different processes without reference to their first moving power, as, for example, bark-mills, cement-mills, colour-mills, corn-mills, oil-mills, saw-mills, sugar-mills, snuff and tobacco mills, &c., which concludes our First Part or division. The Second Part treats of mechanical processes and manufactures. A classification is here again attempted by first describing those mechanical establishments generally spoken of under the term Works, as iron-works, copper-works, and others for the production of metals; works for the production of acids, salts, pigments, &c., employed in Manufactures and for domestic purposes; works for forming artificial substances, as bricks, porcelain, glass, &c.; gunpowder-works, sugar-works, and those for bleaching, dyeing, calico-printing, and for tanning and tawing leather.

Under the denomination of works of public and domestic utility are described gas-works, light-houses, warming and ventilating manufactories, public sewers, iron wharfs, and water-works.

In a subsequent division are described various mechanical processes in metals, as button-making, coining, clock and watch making, gun-making, founding, nail, needle, and pin making, wire-drawing, &c.

The next division relates to the manufacture of fibrous materials, as cotton, flax, silk, woollen, worsted, &c., hat-making, rope-making, and paper-making; and under the head of Miscellaneous Mechanical Processes, are included all such as could not be with propriety given under any of the preceding divisions, such as printing by presses and by

machines, copper-plate and lithographic printing, sculpture, lens and specula grinding, &c.; and, lastly, malting, distilling, biscuit-making by machinery, porter-brewing, &c.

Such is the arrangement which has been adopted in the following pages. How far it has been judicious, must be left to the judgment of others; but, at all events, the alphabetical index will furnish the reader with a ready means of reference; and it is to be hoped he will seldom be disappointed in finding any article which may reasonably be expected to be found in a work bearing the title given to the present volume. As far as lay in our power we have endeavoured to describe the most modern and effective machinery; but we do not flatter ourselves that this has always been done, although we have been most liberally assisted by many proprietors of extensive works, and by the Government Departments in particular. We ought also to acknowledge the aid we have received from different periodical Works, especially from the *Transactions of the Society of Arts*, and from the *Repertory of Arts*.

The practical mechanic will not expect to find in a general Work of this kind such minutiae of delineation as to furnish working drawings of the several machines described, because every such person will be aware of the great extent to which the Work must have been carried to have effected this object, or of the necessity we should have been under of suppressing a great deal of interesting popular matter, and thereby changing altogether the original design of the undertaking, which was to exhibit to the general reader a popular but correct idea of the nature of the processes by means of which our Manufactures have attained to their present state of pre-eminence, with a concise statistical view of their effects on the population, the wealth, and revenue of the British Empire.

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MANUFACTURES

SECTION I.

ON THE GENERAL PRINCIPLES WHICH REGULATE THE APPLICATION OF MACHINERY TO MANUFACTURES AND THE MECHANICAL ARTS.

CHAPTER I.

ON THE MECHANICAL PRINCIPLES.

Manu-
factures.

Sect. I

THERE is, perhaps, no single circumstance which distinguishes our Country so remarkably from all others, as the vast extent to which we have carried our contrivances of Tools and Machines for forming all those conveniencies, of which so large a quantity is consumed by almost every class of the community. The amount of patient thought, of repeated experiment, of happy exertion of genius, by which our Manufactures have been created and carried to their present excellence, is scarcely to be imagined. If we look around the rooms we inhabit, or through those storehouses of every convenience, of every luxury that man can desire, which deck the crowded streets of our larger cities, we shall find in the history of each article, of every fabric, a series of failures which have gradually led the way to excellence; and we shall notice, in the Art of making even the most insignificant, processes calculated to excite our admiration by their simplicity, or to rivet our attention by their unlooked-for results.

The accumulation of skill and science which has been directed to diminish the difficulty of the production of Manufactured goods, has not been beneficial to that Country only in which it is concentrated; distant Kingdoms have participated in its advantages. The luxurious natives of the East,* and the ruder inhabitants of the African desert, are alike indebted to our looms. The produce of our factories seems to have preceded even our most enterprising travellers.† The cotton of India is conveyed by British ships round

* "The Bandana handkerchiefs manufactured at Glasgow have long superseded those which are genuine, and are now consumed in large quantities both by the natives and Chinese." Crawford's *Indian Archipelago*, vol. iii. p. 505.

† Captain Clapperton, when on a visit at the Court of the Sultan Bello, states, "provisions were regularly sent me from the Sultan's table on pewter dishes with the London stamp, and I even had a piece of meat served up on a white wash-hand basin of English manufacture." Clapperton's *Journey*, p. 88.

Manu-
factures.

half our Planet, to be woven by British skill in the factories of Lancashire. It is again set in motion by British capital, and, transported to the very plains whereon it grew, it is repurchased by the lords of the soil which gave it birth, at a cheaper price than that at which their coarser machinery will enable them to Manufacture it themselves.*

Sect. I.

We propose, in the present division of this work, to give a detailed account of the various Manufactures which are carried on in this Country, and a description of the Tools and Machinery by which their operations are conducted. Previously to this, however, we shall endeavour to state the principles on which their success depends, and to trace both the causes and the consequences of the application of machinery to supersede the skill and power of the human arm.

Advantages
of machi-
nery and
manufac-
tures.

1. The utility of Machinery and Manufactures seems to arise from *the addition which they make to human power ;—the economy of human time ;—and the conversion of substances apparently the most common and most worthless into valuable products.*

With respect to the first of these effects, the forces derived from wind, from water, and from steam, present themselves to the mind of every one ; these are, in fact, additions to human power, and will be considered in a future page : there are, however, other sources of its increase, by which the animal force of the individual is made to act with far greater than its unassisted powers, and to these we shall at present confine our observations.

The construction of Palaces, of Temples, and of Tombs, seems to have occupied the earliest attention of Nations just entering on the career of civilisation ; and the enormous blocks of stone moved from their native repositories to minister to the grandeur or piety of the builders, have remained to excite the astonishment of their posterity, even long after the purposes of many of these records, as well as the names of their founders, have been forgotten.

The different degrees of force necessary to move these ponderous masses will have varied according to the Mechanical knowledge of the people employed in their transport ; and that the extent of power required for this purpose is widely different under different circumstances, will appear from the following experiment, which is related by M. Redelet, *Sur L'Art de Bâtir*. A block of squared stone was taken for the subject of experiment, weighing 1080 lbs.

	lbs.
1. Weight of stone	1080
2. In order to drag this stone along the floor of the quarry roughly chiselled, it required a force equal to	758
3. The same stone dragged over a floor of planks required	652
4. The same stone placed on a platform of wood and dragged over a floor of planks, required	606
5. After soaping the two surfaces of wood which slid over each other it required	182
6. The same stone was now placed upon rollers of three inches diameter, when it required to put it in motion along the floor of the quarry	34

* At Calicut, in the East Indies, (whence the cotton cloth called *Calico* derives its name,) the price of labour is *one-seventh* of that in England, yet the market is supplied from British looms.

Manu-
factures.

6. To drag it by these rollers over a wooden floor required	lbs. 28
7. When the stone was mounted on a wooden platform, and the same rollers placed between that and a plank floor, it required	22

Sect. I.

From this experiment it results, that the force necessary to move a stone along the smoothed floor of its quarry is nearly two-thirds of its weight; to move it along a wooden floor, three-fifths; by wood upon wood, five-ninths; if the wooden surfaces are soaped, one-sixth; if rollers are used on the floor of the quarry, it requires one thirty-second part of the weight; if they roll over wood, one-fortieth; and if they roll between wood, one-fiftieth of its weight.

At each increase of knowledge, as well as on the contrivance of every new Tool, human labour becomes abridged. The man who contrived rollers, invented a Tool by which his power was quintupled. The workman who first suggested the employment of soap, or grease, was immediately enabled to move, without exerting a greater effort, more than three times the weight he could before. So sensible are the effects of grease in diminishing friction, that the drivers of sledges in Amsterdam, on which heavy goods are transported, carry in their hand a rope soaked in tallow, which they throw down from time to time before the sledge, in order that by passing over the rope it may become greased.

2. The next use of Machinery and Manufactures is—*the economy which they produce of human time.* So extensive and important is this effect, that we might, if we were inclined to generalize, embrace almost all their advantages under this one head; but the elucidation of principles of less extent will contribute more readily to a knowledge of the subject, and as numerous examples will be presented to the reader in the ensuing pages, we shall restrict our illustrations upon this point.

The Art of using the diamond for cutting glass has undergone, within a few years, a very important improvement. A glazier's apprentice, when using a diamond set in a conical ferrule, as was always the practice about twelve years since, found great difficulty in acquiring the Art of employing it with certainty, and at the end of a seven years' apprenticeship many were found but indifferently skilled in its use. This arose from the difficulty of finding the precise angle at which the diamond cut, and of guiding it along the glass at the proper inclination when that angle was found. Almost the whole of the time consumed, and of the glass destroyed in acquiring the Art of cutting glass, may now be saved by the use of an improved tool. The gem is set in a small piece of squared brass, with its edge nearly parallel to one side. A person skilled in its use now files away one side of the brass, until, by trial, he finds that it will act well, when guided, by keeping this edge pressed against a ruler. The diamond and its mounting are now attached to a stick similar to a pencil, by means of a swivel allowing a small angular motion. Thus the merest tyro, using it in this form, at once applies it at the proper angle, by pressing the side against a ruler; and even though the part he holds in his hand should deviate a little from its proper angle, it communicates no irregularity to the position of the diamond, which rarely fails to do its office when thus employed.

As another example of the economy of time, the use of gunpowder in blasting

Manu-
factures.

rocks may be noticed. Several pounds of that substance may be purchased for a sum acquired by a few days' labour; yet when this is employed for the purpose alluded to, effects are frequently produced which could not, even with the best tools, be accomplished by other means in less than many months. Sect. 1.

Prussiate of
potash.Old tin-
ware.

3. *Instances of the production of valuable matter from the most worthless materials* are constantly occurring. The skins used by the gold-beater are produced from the offal of animals. The hoofs of horses and cattle, and other horny refuse, are employed in the production of the Prussiate of Potash, that beautiful, yellow, crystallized salt, which is exhibited in the shops of some of our chemists. The worn-out sauce-pans and tin-ware of our kitchens, when beyond the reach of the tinker's Art, are not utterly worthless. We sometimes meet carts loaded with old tin kettles and iron coal-scuttles traversing our streets. These have not yet completed their useful course; the less corroded parts are cut into strips, punched with small holes, and varnished with a coarse black varnish, for the use of the trunk-maker, who protects the edges and angles of his boxes with them; the remainder are conveyed to the Manufacturing chemists in the out-skirts of the town, who employ them, in conjunction with pyroligneous acid, in making a black die for the use of Calico printers.

The difference between a Tool and a Machine is not capable of very precise distinction, nor is it necessary, in our popular explanation of them, to limit very strictly their popular sense. A Tool is usually more simple than a Machine; it is generally used with the hand, whilst a Machine is frequently moved by animal or steam power. The simpler Machines are often merely one or more Tools placed in a frame, and acted on by any moving power. In pointing out the advantages of Tools, we shall commence with some of the simplest.

Longitudi-
nal arrange-
ment of
needles

To arrange twenty thousand needles thrown promiscuously into a box, mixed and entangled with each other in every possible direction, in such a form that they shall be all parallel to each other, would, at first sight, appear a most tedious occupation; in fact, if each were to be separated individually, many hours must be consumed in the process. Yet this is an operation which must be performed many times in the Manufacture of needles; and it is accomplished in a few minutes by a very simple Tool, which is, in fact, nothing more than a small flat tray of sheet iron, slightly concave at the bottom. The needles are placed in it and shaken in a peculiar manner, by throwing them up a very little, and giving at the same time a slight longitudinal motion. The shape of the needles assists their arrangement; for if the needles cross each other, (unless, which is exceedingly improbable, they happen to be precisely the same,) they will, when they fall on the bottom of the tray, tend to place themselves side by side, and the hollow form of the tray assists this disposition. As they have no projection in any part to impede this tendency, or to entangle each other, they are, by continually shaking, arranged lengthwise, in three or four minutes. The direction of the shake is now changed, the needles are but little thrown up, but the tray is shaken endways; the result of which is, that in a minute or two the needles which were previously arranged endways become heaped up in a wall, with their ends against the extremity of the tray.

Manu-
factures.

They are now removed by hundreds at a time, by raising them with a broad iron spatula, on which they are retained by the fore-finger of the left hand. Sect. I.

Another process in the same Manufacture furnishes an example of one of the simplest contrivances which can come under the denomination of a Tool. After the needles have been arranged in the manner just described, it is necessary to separate them into two parcels, in order that their points may be all in one direction. This is usually done by women and children. The needles are placed sideways in a heap, on a table, in front of each operator, just as they are arranged by the process above described. From five to ten are rolled towards this person by the fore-finger of the left hand; this separates them a very small space from each other, and each in its turn is pushed lengthwise to the right or to the left, according as its eye is on the right or the left hand. This is the usual process, and in it every needle passes individually under the finger of the operator. A small alteration expedites the process considerably; the child puts on the fore-finger of its right hand a small cloth cap or finger-stall, and rolling from the heap from six to twelve needles, it keeps them down by the fore-finger of the left hand; whilst it presses the fore-finger of the right hand gently against the ends of the needles, those which have their points towards the right hand stick into the finger-stall; and the child, removing the finger of the left hand, allows the needles sticking into the cloth to be slightly raised, and then pushes them towards the left side. Those needles which had their eyes on the right hand do not stick into the finger cover, and are pushed to the heap on the right side previous to the repetition of this process. By means of this simple contrivance each movement of the finger, from one side to the other, carries five or six needles to their proper heap; whereas, in the former method, frequently only one was moved, and rarely more than two or three were transported at one movement to their place. Arranging the points in the same direction.

There occur operations in the Arts in which the assistance of an additional hand would be a great convenience to the workmen, and in these cases Tools or Machines of the simplest kind come to our aid. Vices of different forms, in which the material to be wrought is firmly grasped by screws, are used in almost every workshop; but a more striking example may be found in the trade of a nail-maker.

Some kinds of nails, such as those used for defending the soles of coarse shoes, called Hob-nails, require a particular form of the head, which is made by the stroke of a die. The workman holds the red-hot rod of iron out of which he forms them in his left hand; with his right hand he hammers the end of it into a point, and, cutting a proper length almost off, bends it nearly at right angles. He puts this into a hole in a small stake-iron immediately under a hammer connected with a treadle, and which has sunk in its surface a die corresponding to the intended form of the head; and having given one part of the form to the head by the small hammer in his hand, he moves the treadle with his foot, which disengages the other hammer, and completes the figure of the head: the returning stroke of this hammer strikes the finished nail out of the hole in which it was retained. Without this substitution of his foot for another hand, the workman would, probably, be obliged to heat the nails twice over. Hob-nails.

Manu-
factures.

Sect. I.

Another, although, fortunately, a less general use of Tools for human hands, is to assist the labour of those who are deprived by Nature, or by accident, of some of their limbs. Those who have examined the beautiful contrivances for the Manufacture of shoes by Machinery, which we owe to the fertile invention of Mr. Brunell, must have noticed many instances in which the operatives were enabled to execute their work with precision, although labouring under the disadvantages of the loss of an arm or a leg. A similar instance occurs at Liverpool, at the Institution for the Blind, where a Machine is used by those afflicted with blindness, for weaving sash-lines; it is said to have been the invention of a person suffering under that calamity. Other instances might be mentioned of contrivances for the use, the amusement, or the instruction of the wealthier classes, who labour under the same natural disadvantages. These triumphs of skill and ingenuity deserve a double portion of our admiration when applied to mitigate the severity of natural or accidental misfortune, when they supply the rich with occupation and knowledge, when they relieve the poor from the additional evils of poverty and want.

There exists a natural, although, in point of number, a very unequal division amongst Machines; they may be classed as *those which are employed to produce power*, and as *those which are intended merely to transmit power and execute work*.

The first of these divisions is of great importance, and is very limited in the variety of its species, although some of those species consist of numerous individuals.

Relation of
power to
time.

Of that class of Mechanical agents by which motion is transmitted, the lever, the pulley, the wedge, and many others, it has been demonstrated, that no power is gained by their use, however combined. *Whatever force is applied at one part can only be exerted at some other, diminished by friction and other incidental causes*; and it has been further proved, that *whatever is gained in the rapidity of execution is compensated by the necessity of exerting additional force*.

These two principles, long since placed beyond the reach of doubt, cannot be too constantly borne in mind; and in limiting our attempts to things which are possible, we are still, as we hope to show, possessed of a wide field of inexhaustible research, and of advantages derived from Mechanical skill, which have but just begun their influence on our Arts, and may be pursued without limit,—contributing to the improvement, the advantage, and the happiness of our race.

The Earth's
rotation
the source
of power.

Of those Machines by which we produce power, it may be observed, that although they are to us immense acquisitions, yet in regard to two of them, the powers of wind and water, we merely make use of bodies in a state of motion by Nature; we change their directions in order to render them subservient to our purposes, but we neither add to nor diminish the quantity of motion in existence. When we expose the sails of a wind-mill obliquely to the gale, we check the velocity of a small portion of the atmosphere, we convert its own rectilinear motion into one of rotation in the sails; we thus change the direction of force, but we create no power. The same may be observed with regard to the sails of a vessel; the quantity of motion given to it is precisely the same as that which is destroyed in the atmosphere.

If we avail ourselves of a descending stream to turn a water-wheel, we are appro-

Manu-
factures.

Sect. I.

priating a power which Nature may appear, at first sight, to be uselessly and irreco-
verably wasting, but which, upon due examination, we shall find she is ever repairing
by other processes. The fluid which is falling from a higher to a lower level, carries
with it the velocity due to its revolution with the Earth at a greater distance from its
centre. It will therefore accelerate, although to an almost infinitesimal extent, the
Earth's daily rotation.

The sum of all these increments of velocity, arising from the descent of all the rivers
on the Earth's surface, would in time become perceptible, did not Nature, by the process
of evaporation, raise the waters back to their sources; and thus again, by removing
matter to a greater distance from the centre, destroy the velocity generated by its
previous approach.

The force of vapour is another fertile source of moving power, but even in this it
cannot be maintained that power is created. Water is converted into elastic vapour by
the combustion of fuel. The Chemical changes which take place are constantly increasing
the atmosphere by large quantities of carbonic acid and other gases noxious to animal
life. By what process Nature decomposes or reconverts these elements into a solid
form, is not sufficiently known. The absorption in large quantities of one portion of
them by vegetation is stated to take place; but if the end could be accomplished by
Mechanical force, it is probable the power necessary to produce it would at least equal
that which was generated by the original combustion. Man, therefore, cannot create
power; but, availing himself of his knowledge of Nature's mysteries, he applies his
talents to diverting a small and limited portion of her energies to his own wants; and,
whether he employs the regulated action of steam, or the more rapid and tremendous
effects of gunpowder, he is only producing, in small quantity, compositions and decom-
positions which Nature is incessantly at work in reversing, for the restoration of that
equilibrium, which we cannot doubt is constantly maintained throughout even the
remotest limits of our system.

The operations of Man participate in the character of their author; they are diminutive,
but energetic during the short period of their existence; those of Nature, acting over
vast spaces, and unlimited by time, are ever pursuing their silent and resistless career.

In stating the broad principle, that all combinations of Mechanical contrivances can
only augment the force communicated to the Machine at the expense of the time
employed in producing the effect, it might, perhaps, be imagined, that the assistance
derived from such contrivances is small. This is, however, by no means the case: the
almost unlimited variety they afford enables us to exert to the greatest advantage the
forces we employ. Although there is a limit beyond which it is impossible to reduce
the power necessary to produce any given effect, yet it seldom happens that the methods
first employed at all approach that limit. In dividing the knotted root of a tree for the
purposes of fuel, how very different will be the time consumed according to the nature
of the Tool made use of. The hatchet, or the adze, will divide it into small parts, but
will consume a large portion of the workman's time. The saw will answer the same
purpose more effectually and more quickly; this, in its turn, is superseded by the wedge,

Manu-
factures.

which rends it in a still shorter time. If the circumstances are favourable, and the workman skilful, the time and expense may be still further reduced by the use of a small quantity of gunpowder exploded in holes judiciously placed in the block. Sect. I.

Packing and
transport of
cotton.

When a mass of matter is moved a certain force must be expended, and upon the proper economy of this the price of transport depends. A Country must, however, have reached a high degree of civilisation before it will have approached this limit. The cotton of Java is carried in junks to the coast of China, but from the circumstance of the seed not being previously separated, three quarters of the weight is not cotton. This might, perhaps, be justified by the want of Machinery to separate it in Java, or by the relative cost of the operation in the two Countries. But the cotton itself, as packed by the Chinese, occupies three times the bulk of an equal quantity shipped by Europeans for their own markets. Thus the freight of a given quantity of cotton costs the Chinese nearly twelve times the price to which, by a proper attention to Mechanical methods, it might be reduced.*

We shall now offer to our readers a general view of the various advantages which result from the use of Machinery.

I. OF ACCUMULATING POWER.

Fly neces-
sary in
rolling iron.

Whenever the work to be done requires more force for its execution than can be generated in the time necessary for its completion, recourse must be had to some Mechanical method of preserving and condensing a part of the power exerted previously to the commencement of the process. This is most frequently accomplished by a fly-wheel, which is in fact nothing more than a wheel having a very heavy rim, so that the greater part of its weight is near the circumference. It requires great power applied for some time to set this in rapid motion, and when moving with considerable velocity, if its force is concentrated on a point, its effects are exceedingly powerful. In some of the iron-works, where the power of the steam-engine is a little too small for the rollers which it drives, it is usual to set it at work a short time before the red-hot iron is ready to be removed from the furnace to the rollers, and to allow it to work with great rapidity until the fly has acquired a velocity rather alarming to those unused to such establishments. On passing the softened mass of iron through the first groove, the engine receives a great and very perceptible check, and its speed is diminished at the next and at each succeeding passage, until the iron bar is reduced to such a size that the ordinary power of the engine is sufficient to roll it.

Also in
punching
plate iron.

The powerful effect of a large fly-wheel when its force can be concentrated in a point, was curiously illustrated at one of the largest of our Manufactories of steam-engines. The proprietor was showing to a friend the method of punching holes in iron plates for the boilers of steam-engines. He held in his hand a piece of sheet iron three-eighths of an inch thick, which he placed under the punch; observing, after several holes had been made, that the punch made its perforations more and more slowly, he called to the

* Crawford's *Indian Archipelago*.

Manu-
factures.

engine-man to know what made the engine work so sluggishly, when it was found that the fly-wheel and punching apparatus had been detached from the steam-engine just at the commencement of his experiment.

Sect. I.

Another mode of accumulating power arises from lifting a weight and then allowing it to fall. A man even with a heavy hammer might strike repeated blows upon the head of a pile without producing any effect. But if he raises a much heavier hammer to a much greater height, its fall, though far less frequently repeated, will produce the desired effect.

II. OF THE REGULATING POWER.

Uniformity and steadiness in the rate at which Machinery works are essential both for its success and its duration.

The beautiful contrivance of Mr. Watt, who invented the *governor* of the steam-engine, must immediately occur to all who are familiar with that admirable Machine: as it will be fully described in another part of this work we need at present only allude to it.

The regularity of the supply of fuel to the fire under the boilers of steam-engines contributes to the uniformity of their rate, and also economises the consumption of coal. Several patents have been taken out for methods of regulating this supply. The general principle is to make the engine supply the fire by means of a hopper, with small quantities of fuel at regular intervals, and to diminish this supply when it works quickly. One of the incidental advantages of this plan is, that by throwing on a very small quantity of coal at a time, the smoke is almost entirely consumed.

The dampers of ashpits and chimneys are in some cases connected with Machines in order to regulate their speed.

Another contrivance for regulating the effect of Machinery consists in a vane, or a fly of little weight but presenting a large surface. This revolves rapidly, and soon acquires a uniform rate, which it cannot greatly exceed; because any addition to its velocity produces a much greater addition to the resistance which it meets with from the air. The interval between the strokes on the bell of a clock is regulated by this means; and the fly is so contrived, that this interval may be altered by presenting the arms of it more or less obliquely to the direction in which they move.

This kind of fly, or vane, is generally used in the smaller pieces of Mechanism, and, unlike the heavy fly, it is a destroyer instead of a preserver of force. It is the regulator used in musical boxes, and in almost all Mechanical toys.

Another very beautiful contrivance for regulating the number of strokes made by a steam-engine is used in Cornwall, it is called the *cataract*, and depends on the time required to fill a vessel plunged in water, the valve through which the fluid is admitted being adjustable at the will of the engine-man.

III. INCREASE OF VELOCITY.

The fatigue produced on the muscles of the human frame does not altogether depend on the actual force exerted at each effort, but partly on the frequency with which it is exerted. The exertion necessary to accomplish every operation consists of two parts: one of these is the propulsion of the Tool or instrument used; and the other is the motion of some limb of the animal producing the action. If we take as an example the act of driving a nail into a piece of wood, one of these is, the *propelling* the hammer head against the nail; the other is, *raising* the arm in order to lift the hammer. If the weight of the hammer is considerable, this *latter* part will cause the greatest portion of the exertion. If the hammer is light, the exertion of *raising* the arm will produce the greatest part of the fatigue. It does therefore happen, that operations requiring very trifling force, if frequently repeated, will tire more effectually than more laborious work. There is also a degree of rapidity beyond which the action of the muscles cannot be pressed.

Tags for
boot-laces.

It is of considerable importance for the economy of labour, to adjust the weight of that part of the animal's body which is moved, the weight of the Tool it urges, and the frequency of repetition of these efforts, so as to produce the greatest effect. An instance of the saving of time by making the same motion of the arm execute two operations instead of one, occurs in the simple Art of making the tags of boot-laces; they consist, as is well known, of very thin, tinned, plate iron, and used to be cut out of long strips of that material into pieces of such a breadth that when bent round they just enclosed the lace. Two pieces of steel have recently been fixed to the side of the shears, by which each piece of tin as soon as it is cut is bent into a semi-cylindrical form. The additional power required for this operation is almost insensible, and it is executed by the same motion of the arm which produces the cut. This work is usually performed by women and children, and with the improved Tool more than three times the quantity is produced in a given time.* Whenever the work is itself light it becomes necessary, in order to economise time, to increase the velocity. Twisting the fibres of wool by the fingers would be a most tedious operation: in the common spinning-wheel the velocity of the foot is moderate, but by a very simple contrivance that of the thread is most rapid. A piece of cat-gut passing round a large wheel and then round a small spindle effects this change. This contrivance is common to a multitude of Machines, some of them very simple. In large shops for the retail of ribands it is necessary at short intervals to "take stock," that is, to measure and rewind every piece of riband, an operation which, even with this mode of shortening it, is sufficiently tiresome, but which without it would be almost impossible from its expense. The small balls of sewing cotton, so cheap and so beautifully wound, are formed by a machine on the same principle, and but a few steps more complicated.

* See *Transactions of the Society of Arts*, 1826.

Manu-
factures.

Sect. I.

In turning from the smaller instruments in frequent use to the larger and more important Machines, the economy of increasing the velocity becomes more striking. In converting cast into wrought iron, a mass of metal of about a hundred weight is heated almost to a white heat, and placed under a heavy hammer moved by water or steam power. This is raised by a projection on a revolving axis; and if the hammer only derived its momentum from the space through which it fell, it would require a considerably greater time to give a blow. But as it is important that the softened mass of red-hot iron should receive as many blows as possible before it cools, the form of the *cam* or projection on the axis is such, that instead of *lifting* the hammer to a small height it throws it up with a jerk, and almost the instant after it strikes against a large beam, which acts as a powerful spring, and impels it down on the iron with great velocity; by this means about double the number of strokes can be made in a given time. In the smaller tilt-hammers this is carried still further: by striking the tail of the tilt-hammer forcibly against a small steel anvil, it rebounds with such velocity, that from three to five hundred strokes are made in a minute.

Velocity of
strokes of
tilt-ham-
mers.

In the Manufacture of anchors, an Art in which this system is of still greater importance, it has only been applied recently.

IV. DIMINUTION OF VELOCITY.

The most frequent reason for employing contrivances for diminishing velocity, arises from the necessity of overcoming great resistances with small power.

Systems of pulleys, the crane, and many other illustrations present themselves, which more strictly belong to others of the causes which we have assigned for the advantages of Machinery.

The common smoke-jack is an instrument in which the velocity communicated is too great for the purpose required, and it is transmitted through wheels which reduce it to a more moderate rate.

Smoke-jack

V. SPREADING THE ACTION OF A FORCE EXERTED FOR A FEW MINUTES OVER A LARGE TIME.

This is one of the most common and most useful of the employments of Machinery. The half minute which we daily devote to the winding up of our watches is an exertion of labour almost insensible, yet by the aid of a few wheels its effect is spread over the twenty-four hours. In our clocks this extension of the time of action of the original force impressed is carried still further; the better kind usually require winding up once in eight days, and some are occasionally made to continue in action during a month, or even a year. Another familiar illustration may be noticed in our domestic furniture: the common jack by which our meat is roasted, is a contrivance to enable the cook in a few minutes to exert a force which the Machine retails out during the

Common
jack.

Manu-
factures.

succeeding hour in turning the loaded spit: thus enabling her to bestow her undivided attention on her other duties. A great number of automata and other Mechanical toys moved by springs may be classed under this division.

Sect. I.

VI. SAVING TIME IN NATURAL OPERATIONS.

The process of Tanning will furnish us with a striking illustration of the power of Machinery in producing this effect. The object of the Art is to combine a certain Tanning principle with every particle of the skin to be tanned. This, in the ordinary process, is accomplished by allowing the skins to soak in pits containing a solution of Tanning matter; they remain in the pits six, twelve, or eighteen months, and in some instances (if the hides are very thick) they are exposed to the operation for two years, or even during a longer period. This length of time seems to be required in order to allow the Tanning matter to penetrate into the interior of a thick hide.

Tanning in
vessels ex-
hausted of
air.

The improved process consists in placing the hides with the solution of Tan in close vessels, and then exhausting the air. The effect of this is to withdraw any air which might be contained in the pores of the hides, and to employ the pressure of the atmosphere to aid capillary attraction in forcing the Tan into the interior of the skins. The effect of the additional force thus brought into action can be equal only to one atmosphere, but a further improvement has been made: The vessel containing the hides is, after exhaustion, filled up with a solution of Tan; a small additional quantity is then injected with a forcing pump. By these means any degree of pressure may be given which the containing vessel is capable of supporting; and it has been found, that by employing such a method the thickest hides may be Tanned in six weeks or two months.

The operation of Bleaching linen in the open air is one for which considerable time is necessary, and although it does not require much labour, yet from the risk of damage and of robbery from long exposure, a mode of shortening the process was highly desirable. The method now practised, although not Mechanical, is such a remarkable instance of the application of Science to the practical purposes of Manufactures, that in mentioning the advantages derived from shortening natural operations, it would have been scarcely pardonable to omit alluding to the beautiful application of chlorine in combination with lime to processes of Bleaching.

Making salt.

Another instance more strictly Mechanical occurs in some Countries where fuel is expensive, and the heat of the Sun is not sufficient to evaporate the water from brine springs. It is first pumped up to a reservoir, and then allowed to fall in small streams through fagots. Thus it becomes divided, and, presenting a large surface, evaporation is facilitated, and the brine which is collected in the vessels below the fagots is stronger than that which was pumped up. After thus getting rid of a large part of the water, the remaining portion is driven off by boiling. The success of this operation depends on the circumstance of the atmosphere not being saturated with moisture: if the air, at the

Manu-
factures.

Sect. I.

time during which the brine falls through the fagots, holds in solution as much moisture as it can contain in an invisible state, none can be absorbed from the salt water, and the labour expended in pumping is entirely wasted. The state of the air, as to dryness, is therefore an important consideration in fixing the time at which this operation is to be performed; and an attentive examination of its state, by means of the Hygrometer, might be productive of some economy of labour.

VII. EXERTING FORCES TOO LARGE FOR HUMAN POWER.

It requires some skill and a considerable apparatus to enable many men to exert their whole force at a given point, and when this number amounts to hundreds or to thousands additional difficulties present themselves. If ten thousand men were hired to act simultaneously, it would be exceedingly difficult to discover whether each exerted his whole force, and consequently, to be assured that each man exerted the force for which he was paid. And if still larger bodies of men or animals were necessary, not only would the difficulty of directing them become greater, but the expense would increase from the necessity of transporting food for their subsistence.

In all our larger Manufactories numerous instances occur of the application of the power of steam to overcome resistances which it would require far greater expense to surmount by means of animal labour. The twisting of the largest cables, the rolling, hammering and cutting large masses of iron, the draining of mines, all require enormous exertions of physical force continued for considerable periods of time. Other means are had recourse to when the force required is great, and the space through which it is to act is small. The Hydraulic Press of Bramah can, by the exertion of one man, produce a pressure of 1500 atmospheres, and with such an instrument a cylinder of wrought iron three inches thick has been burst. In rivetting together the iron plates out of which-steam engine boilers are made, it is necessary to produce as close a joint as possible. This is accomplished by using the rivets red-hot; and while they are in that state the two plates of iron are rivetted together, and the contraction which the rivet undergoes in cooling draws them together with a force which is limited only by the tenacity of the iron of which the rivet itself is made.

Hydraulic
press.Rivetting
boilers.

VIII. EXECUTING OPERATIONS TOO DELICATE FOR HUMAN TOUCH.

It is not alone in the greater operations of the Engineer or the Manufacturer, that those vast powers which Man has called into action, in availing himself of the agency of steam, are fully developed. Wherever the individual operation, demanding little force for its own performance, is to be multiplied in almost endless repetition, commensurate power is required. It is the same "giant arm which twists the largest cable," that spins from the cotton plant an "almost gossamer thread." Obedient to the hand which called into action its resistless powers, it contends with the ocean and the storm, and rides triumphant through dangers and difficulties unattempted by the older modes of

Manu-
factures.

navigation.* It is the same engine that, in its more regulated action, weaves the canvass it may one day supersede, and, with almost fairy fingers, entwines the meshes of the most delicate fabric that adorns the female form.†

Sect. I.

Wetting
Bank-note
paper.

The process of printing on silver paper, which is necessary for Bank-notes, is attended with some inconvenience, from the necessity of damping the paper previously to taking the impression. It was difficult to do this uniformly; and in the old process of dipping a parcel of several sheets together into a vessel of water, the outside sheets, getting much more wet than the others, were very apt to be torn. A method has been adopted at the Bank of Ireland which obviates this inconvenience. The whole quantity of paper to be damped is placed in a close vessel from which the air is exhausted; water is then admitted and every leaf is completely wetted; the paper is then removed to a press, and all the superfluous moisture is squeezed out.

IX. REGISTERING OPERATIONS.

Counting
machines.

One of the singular advantages we derive from Machinery is in the check which it affords against the inattention, or the idleness, of human agents. Few occupations are more wearisome than counting a series of repetitions of the same fact; the number of paces we walk affords a tolerably good measure of distance passed over, but the value of this is much enhanced by possessing an instrument, the Pedometer, which will count for us the number we have made. An instrument similar in its object, but differing in its construction, has been used for counting the number of strokes made by a steam-engine, and the number of coins struck in a Press.

* The Fifth Report of the Select Committee of the House of Commons on the Holyhead Roads furnishes ample proof of the great superiority of steam-boats over sailing vessels. The following extracts are taken from the evidence of Captain Rogers, the commander of one of the packets.

Question. Be so good as to acquaint the committee in what manner the communication has been kept open between Holyhead and Dublin by steam-packets, and what has been the success of the experiment of establishing them on that station.

Answer. We have done every thing that could be done, *by steam-boats*; and they will go, no doubt, when a sailing vessel will not,—that has been proved.

Quest. Are you not perfectly satisfied, from the experience you have had, that the steam-vessel you command is capable of performing what no sailing vessel can do?

Ans. Yes.

Quest. During your passage from Gravesend to the Downs could any square-rigged vessel, from a first-rate down to a sloop of war, have performed the voyage you did in the time you did it in the steam-boat?

Ans. No; it was impossible. In the Downs we passed several Indiamen, and 150 sail there that could not move down the Channel; and at the back of Dungeness we passed 120 more.

Quest. At the time you performed that voyage, with the weather you have described, from the Downs to Milford, if that weather had continued twelve months would any square-rigged vessel have performed it?

Ans. They would have been a long time about it; probably, would have been weeks instead of days. A sailing vessel would not have beat up to Milford, as we did, in twelve months.

† The importance and diversified applications of the steam-engine were most ably enforced in the speeches made at a Public meeting held June, 1824, for the purpose of proposing the erection of a monument to the memory of James Watt; these were subsequently printed.

Manu-
factures.

Sect. I.

Another instrument for registering is used in some establishments for calendering and embossing. Many hundred thousand yards of calicoes and stuffs pass weekly through these operations, and as the amount paid for the process is small, the time spent in measuring them would bear a considerable proportion to the profit. A Machine has been contrived for measuring and registering the length of the goods as they pass rapidly through the hands of the operator, and all chance of erroneous counting is thus avoided.

Perhaps the most useful contrivance of this kind, is one for ascertaining the vigilance of a watchman. It is a piece of Mechanism connected with a clock placed in an apartment to which the watchman has not access; but he is ordered to pull a string situated in a certain part of his round once in every hour. The instrument, aptly called a *tell-tale*, informs the owner whether the man has missed any, and what, hours during the night.

X. ECONOMY OF THE MATERIALS EMPLOYED.

The precision with which all operations by Machinery are executed, and the exact similarity of the articles thus made, produce a degree of economy in the consumption of the raw material which is in some cases of great importance.

The earliest mode of cutting the trunk of a tree into planks, was by the use of the hatchet or the adze. It might, perhaps, be first split into three or four portions, and then each portion was reduced to a uniform surface by those instruments. With such means the quantity of plank produced would probably not equal the quantity of the raw material wasted by the process, and, if the planks were thin, would certainly fall far short of it. An improved Tool, the saw, completely reverses the case: in converting a tree into thick planks it causes a waste of a very small fractional part; and even in reducing it to planks of only an inch in thickness, it does not waste more than an eighth part of the raw material.

The rapid improvements which have taken place in the Printing Press during the last twenty years, afford another instance of saving in the materials consumed, which is interesting from its connection with Literature, and valuable because admitted and well ascertained by measurement.

In the old method of inking type, by large hemispherical balls stuffed and covered with leather, the printer, after taking a small portion of ink from the ink-block, was continually rolling them in various directions against each other, in order that a thin layer of ink might be uniformly spread over their surface. This he again transferred to the type by a kind of rolling action. In such a process, even admitting considerable skill in the operator, it could not fail to happen that a large quantity of ink should get near the edges of the balls, which, not being transferred to the type, became hard and useless, and was taken off in the form of a thick black crust. Another inconvenience also arose,—the quantity of ink spread on the block not being regulated by measure, and the number and direction of the transits of the inking balls over each other depending on

Mode of
spreading
ink on type.

Manu-
factures.

Sect. I.

the will of the operator and being irregular, it was impossible to place on the type a uniform layer of ink, of exactly the quantity sufficient for the impression. The introduction of cylindrical rollers of an elastic substance, formed by the mixture of glue and treacle, superseded the inking balls, and produced considerable saving in the consumption of ink:—but the most perfect economy was to be produced only by mechanism.

When Printing Presses moved by the power of steam were introduced, the action of these rollers was found well calculated to be performed by the Machine, and a reservoir of ink was formed from which one roller regularly abstracted a small quantity at each impression. From three to five other rollers spread this portion uniformly over the slab (by most ingenious contrivances varied in almost each kind of Press,) and another travelling roller, having fed itself on the slab, passed and repassed over the type just previously to its giving the impression on the paper. The following is an account of the results of an accurate experiment made at one of the largest Printing establishments in the Metropolis. Two hundred reams of paper were printed off, the old method of inking with balls being employed; two hundred reams of the same paper, and for the same book, were then printed off in the Presses which inked their own type.

The consumption of ink by the Machine was to that by the balls as four to nine, or rather less than one-half.

In order to show that this plan of inking puts the proper quantity of ink upon the type, we must prove first that it is not too little:—this would soon have been discovered from the complaints of the Public and the Booksellers; and, secondly,—that it is not too much. This latter point is satisfactorily established by a reference to the frequency of change of what is called “the set-off sheet” in the old method. A few hours after one side of a sheet of paper has been printed upon, the ink is sufficiently dry to allow it to receive the impression upon the other, and as considerable pressure is made use of, the tympan on which the side first printed is laid, is guarded from soiling it by a sheet of paper called the set-off sheet. This paper receives in succession every sheet of the work to be printed, and acquires from them more or less of the ink, according to their dryness or the quantity upon them. It was usual in the former process, after about one hundred impressions, to change the set-off sheet, which in that time became too much soiled for further use. In the new method of printing by Machinery no set-off sheet is used, but a blanket is employed as its substitute: this does not require changing above once in five thousand impressions, and instances have occurred of its remaining sufficiently clean for twenty thousand. Here, then, is proof that the quantity of superfluous ink put upon the paper in Machine-printing is so small, that if multiplied by five thousand, and in some instances even by twenty thousand, it is only sufficient to render useless a single piece of clean cloth.*

* In the very best kind of printing it is necessary in the old method to change the set-off sheet once in twelve times. In printing the same kind of work by Machinery the blanket is changed once in 2000.

XI. THE IDENTITY OF THE WORK WHEN IT IS OF THE SAME KIND.

Nothing is more remarkable, and yet less unexpected, than the perfect identity of things manufactured by the same Tool. If the top of a box is to be made to fit over the lower part, it may be done by gradually advancing the tool of the sliding rest; the proper degree of tightness between the box and its lid being found by trial. After this adjustment, if a thousand boxes are made, no additional care is required; the tool is always carried up to the stop, and each box will be equally adapted to every lid.

The same identity pervades all the arts of Printing; the impressions from the same block, or the same copper plate, have a similarity which no labour could produce by hand. The minutest traces are transferred to all the impressions, and no omission can arise from the inattention or unskilfulness of the operator. The steel punch, with which the card wadding for a fowling-piece is cut, if it once perform its office with accuracy, constantly reproduces the same exact circle.

XII. ACCURACY OF THE WORK WHEN OF DIFFERENT KINDS.

The accuracy with which Machinery executes its work is, perhaps, one of its most important advantages: it may, however, be contended that a considerable portion of this advantage may be resolved into a saving of time.

It generally happens, that any improvement in tools increases the quantity of work done in a given time. Without tools, that is, by the mere efforts of the human hand, there are, undoubtedly, multitudes of things which it would be impossible to make. Add to the human hand the rudest cutting instrument, and its powers are enlarged: the fabrication of many things then becomes easy, and that of some possible with great labour. Add the saw to the knife or the hatchet, and other works become possible, and a new course of difficult operations is brought into view, whilst many of the former difficulties are removed. This observation is applicable even to the most perfect tools or machines. It would be *possible* for a very skilful workman with files and polishing substances to form a cylinder out of a piece of steel, but the time which this would require would be so considerable, and the number of failures would probably be so large, that for all practical purposes such a mode of producing a steel cylinder might be said to be impossible.

The same process by the aid of the lathe and the sliding rest is the every-day employment of hundreds of workmen.

It is more easy to make a good circle than to produce a straight line. Of all the operations of art, that of turning is the most perfect. If two surfaces are worked against each other, whatever may have been their figure at the commencement, there exists a tendency in them to become portions of spheres. Either of them may become convex, and the other concave, with various degrees of curvature. A plain surface is

Manu-
factures.

Sect. I.

the line of separation between convexity and concavity, and is most difficult to hit. A similar difficulty takes place in figuring specula for telescopes; the parabola is the surface which separates the hyperbolic from the elliptic figure, and is the most difficult to form. If a spindle not cylindrical at its end is pressed into a hole not circular, and if the spindle be kept constantly turning, there is a tendency in these two bodies so situated to become conical, or to have circular sections. If a triangular pointed piece of iron be worked round in a circular hole the edges will gradually wear, and it will become conical. These facts, if they do not explain, at least illustrate the principles on which the excellence of work formed in the lathe depends

The operation of printing the Numbers on Bank-notes is one which requires perfect accuracy; and although each Number differs from all the others, it is accomplished by a few wheels.

OF COPYING.

The two last sources of excellence in the work produced by Machinery depend on a principle which pervades a very large portion of all Manufactures, and is one upon which the cheapness of the articles produced seems greatly to depend. The principle to which we allude is the system of COPYING, taken in its most extensive sense. Almost unlimited pains are, in some instances, bestowed on the original, from which a series of Copies is to be produced; and the larger the number of these Copies, the more care and pains can the manufacturer afford to lavish upon the original. It may thus happen, that the instrument, or tool actually producing the work, shall cost five or even ten thousand times the price of each individual specimen of its power.

As the system of Copying is of so much importance, and of such extensive use in the Arts, we shall endeavour to classify a considerable number of those processes in which it is employed; not, however, pretending to give a complete list, and restricting ourselves to the shortest possible detail which will be consistent with a due regard to making the subject intelligible.

Operations of Copying take place under the following circumstances:—by Printing,—by Casting,—by Moulding,—by Stamping,—by Punching,—with elongation,—with altered dimensions.

OF COPYING BY PRINTING.

Of Copying by Printing.—The Art of Printing, in all its numerous departments, is essentially an Art of Copying. Under its two great divisions, Printing from hollow lines, as in copper-plate, and Printing from surface, are comprised numerous Arts.

Copper-
plate Print-
ing.

Copper-plate Printing.—In this instance the Copies are made by transferring by pressure a thick ink from the hollows and lines cut in the copper to sheets of paper. An artist will sometimes exhaust the labour of one or two years upon engraving a Plate, which will not, in some cases, furnish above five hundred Copies in a state of perfection.

Engraving on steel.—This is in most respects similar to engraving on copper, except that the number of Copies is far less limited. A Bank-note engraved as a copper-plate will not give above three thousand impressions without a sensible deterioration. Two impressions from a Bank-note engraved on steel were examined by one of the best artists of the present day, and he could not say, with any confidence, which was the earliest impression. One of these was a proof from amongst the first thousand, the other was taken after between seventy and eighty thousand had been printed off.

Sect. I.
Printing
from steel.

Music Printing.—Music is printed from Pewter Plates, on which the characters have been impressed by steel punches. The metal being much softer than copper is liable to scratches, which detain a small portion of the ink. This is the reason of the dirty appearance of printed music. A new process has recently been invented by Mr. Cowper, by which this inconvenience will be avoided. The improved method, which gives sharpness to the characters, is still an art of copying; but it is effected by surface Printing.

Music
Printing.

Calico Printing from cylinders.—Many of the patterns on printed calicoes are Copies by printing from copper cylinders about four or five inches in diameter, on which has been previously engraved the desired pattern. One portion of the cylinder is exposed to the ink, whilst an elastic scraper of stuffed leather, by being pressed forcibly against another part, removes all superfluous ink from the surface previous to its reaching the cloth. A piece of calico twenty-eight yards in length rolls through this press in four or five minutes.

Calico
Printing
from copper
cylinders.

Printing from perforated sheets of metal.—Very thin brass is sometimes perforated in the form of letters, usually a name; this is placed on any substance which it is required to mark, and a brush dipped in some paint is passed over the brass. Those parts which are cut away admit the paint, and thus a copy of the name appears on the substance below.

Stencilling.

This method, which affords rather a coarse copy, is sometimes used for paper with which rooms are covered, and more especially for the borders. If a portion is required to match an old pattern, this is, perhaps, the most economical way of producing it.

The beautiful red cotton handkerchiefs dyed at Glasgow have their pattern given to them by a process similar to this, except that instead of *printing* from a pattern the reverse operation, that of *discharging* a part of the colour from a cloth already dyed, is performed. A number of handkerchiefs are pressed with immense force between two plates of metal, which are similarly perforated with round or lozenge-shaped holes, according to the intended pattern. The upper plate of metal is surrounded by a rim, and a fluid which has the property of discharging the red dye is poured upon that plate. This liquid passes through the holes in the metal, and also through the calico; but owing to the great pressure opposite all the parts of the plates not cut away it does not spread itself beyond the pattern. After this the handkerchiefs are washed, and the Pattern of each is a copy of the perforated metal plate used in the process.

Patterns
on red cot-
ton handker-
chiefs.

The other department, or that of *Printing from surface*, is of more frequent application in the Arts.

Manu-
factures.
Wood-cuts.

Printing from wooden blocks.—A block of box-wood is in this instance the substance out of which the pattern is formed: the design being sketched upon it, the workman cuts away with sharp tools every part except the lines to be represented in the impression. This is exactly the reverse of the process of engraving on copper, in which every line to be represented is cut away. The ink instead of filling the cavities cut in the wood is spread upon the surface which remains, and is thence transferred to the paper.

Common
Printing.

Printing from movable type.—This is the most important in its influence of all the Arts of Copying. It possesses a singular peculiarity, which arises from the immense subdivision of the parts that form the pattern. After that pattern has furnished thousands of Copies, the same individual elements may be arranged again and again in other forms, and thus furnish multitudes of originals, from each of which thousands of their copied impressions may flow.

Stereotype
printing.

Printing from stereotype.—This mode of producing Copies is very similar to the preceding: but as the original pattern is incapable of change, it is applied only to cases where an extraordinary number of Copies are demanded, or where the work consists of figures, and it is of great importance to ensure accuracy. Individual alterations may be made in it; and thus Mathematical Tables may, by the gradual extirpation of error, at last become perfect. This mode of producing Copies possesses, in common with that by movable types, the advantage of being capable of being used in conjunction with wood-cuts, a union frequently of considerable importance, and which is not so readily accomplished with engravings on copper.

Printing
calico from
blocks.

Calico Printing from blocks.—This is a mode of Copying by surface Printing from the ends of small pieces of copper wire, of various forms, fixed into a block of wood. They are all of one uniform height, about the eighth part of an inch above the surface of the wood, and are arranged by the maker into any required pattern. If the block be placed upon a piece of fine woollen cloth, on which ink of any colour has been uniformly spread, the projecting copper wires receive a portion which they give up when applied to the calico to be printed. By the former method of Printing on calico, only one colour could be used; but by this plan, after the flower of a rose, for example, has been printed with one set of blocks, the leaves may be printed of another colour by a different set.

Printing
oil-cloth.

Printing Oil-cloth.—After the canvass, which forms the basis of oil-cloth, has been covered with paint of one uniform tint, the remainder of the processes, which it passes through, are a series of Copying by surface Printing from patterns formed upon wooden blocks very similar to those employed by the calico printer. Each colour requires a set of blocks; and thus those oil-cloths with the greatest variety of colours are most expensive.

There are several other varieties of Printing which we shall briefly notice as Arts of Copying; which although not strictly surface Printing, yet are more allied to it than to that from copper plates.

Letter copy-
ing.

Letter Copying.—In one of the modes of performing this process, a sheet of very thin paper is damped, and placed upon the writing to be copied. The two papers are then

Manu- passed through a rolling press, and a portion of the ink from one paper is transferred *Sect. I.*
factures, to the other. The writing is of course reversed by this process; but the paper to which
 it is transferred being thin, it is visible on the other side in an uninverted position.

Another common mode of Copying letters is by placing a sheet of paper covered on both sides with a black substance prepared from lamp-black, between a sheet of thin paper and the paper on which the letter to be despatched is to be written. If the upper or thin sheet be written upon with any hard pointed substance, the words written with this style will be impressed from the black paper upon both those adjoining it. The translucency of the upper sheet, in this instance, is necessary to obviate the inconvenience of the reversing of the writing. Both these Arts are very limited in their extent, two or three being the utmost number of repetitions they allow.

Printing on China.—This is an Art of Copying which is carried to a very great extent. *Printing on China.*
 As the surfaces to which the impression is to be conveyed are often curved, and sometimes even fluted, the ink, or paint, is first transferred from the copper to some flexible substance, such as paper, or an elastic compound of glue and treacle. It is almost immediately conveyed from this to the unbaked biscuit, to which it more readily adheres.

Lithographic Printing.—This is another mode of producing Copies almost unlimited in *Lithographic Printing.*
 number. The original which supplies the Copies is a drawing on stone, executed with such materials that when water is poured over the stone it shall not wet the lines of the drawing. When a roller covered with printing ink is passed over the stone, the water prevents it from adhering to the uncovered portions; while the ink used in the drawing is of such a nature that the printing ink adheres to it. In this state, if a sheet of paper be placed upon it, and it is then passed under a press, the printing ink is transferred to the paper, leaving the ink used in the drawing adhering to the stone.

OF COPYING BY CASTING.

The Art of Casting, by pouring substances in a fluid state into a mould which retains them until they become solid, is essentially an Art of Copying. It also happens that the thing produced resembles entirely, as to shape, the pattern from which it was formed.

Of Casting iron and other metals.—Patterns made from drawings are the originals from *Casting metals.*
 which the moulds for Casting are made, so that, in fact, the Casting itself is the Copy of the mould, and the mould is the Copy of the wooden pattern. In castings of iron and metals for the coarser purposes, and, if they are afterwards to be worked, even for the finer machines, the exact resemblance amongst the things produced which takes place in many of the Arts to which we have alluded, does not happen, nor is this necessary. As the metals shrink in cooling, the pattern is made larger than the intended copy; and in extricating it from the sand in which it is moulded, some little difference will occur in the size of the cavity which it leaves.

In smaller work, where accuracy is more requisite, and where few or no after-operations are to be performed, a mould of metal is employed which has been formed with

Manu-
factures.

Sect. I.

considerable care. Thus, in casting bullets, which ought to be perfectly spherical and smooth, an iron instrument is used in which a cavity has been cut and ground with considerable care; and in order to obviate the evil which would otherwise result from the contraction in cooling, a jet is left which may supply the deficiency arising from that cause, and which is afterwards cut off. The leaden toys for children are cast in brass moulds which open, and which have been graved into the figures designed.

Plaster of
Paris.

Casting with plaster.—This is a mode of Copying applied to a variety of purposes;—to produce accurate representations of the human form,—of statues,—or of rare fossils,—to which latter purpose it has lately been applied with great advantage.

In all casting, the first process is to make the mould, and plaster is the substance which is almost always employed in the cases now under consideration. The property which it possesses of remaining for a short time in a state of fluidity, renders it admirably adapted to this purpose, and adhesion is effectually prevented by oiling the surface on which it is poured. The mould formed round the original, removed in separate pieces and then reunited, is that in which the Copy is cast.

Casting in
wax.

Casting in wax.—This mode of Copying, aided by proper colouring, offers the most successful imitations of many objects of Natural History, and gives an air of reality to them which might deceive even the most instructed. Numerous figures of remarkable persons, having the face and hands formed in wax, have been exhibited at various times, and the resemblances have in some instances been most striking. But whoever would see the Art of Copying in wax carried to the highest perfection, should examine the beautiful collection of fruit at the House of the *Horticultural Society*; the model of the magnificent flower of the plant which forms the new genus *Rafflesia*; or the waxen models of the internal parts of the human body which adorn the Anatomical Gallery of the *Jardin des Plantes*, and the *Museum* at Florence.

The Art of imitation by wax does not usually afford the multitude of Copies which flow from many similar operations. This number is checked by the subsequent stages of the process, which, ceasing to have the character of Copying by a tool or pattern, consequently become more expensive. Form alone is given by Casting; the colouring must be the work of the pencil, guided by the artist in each individual production.

OF COPYING BY MOULDING.

This method of producing multitudes of individuals having an exact resemblance in external shape, is adopted very widely in the Arts. The substances employed are either naturally or by artificial preparation, in a soft or plastic state; they are then compressed by mechanical force, sometimes assisted by heat, into a mould of the required form.

Brick-
making.

Of bricks and tiles.—An oblong box of wood fitting upon a bottom fixed to the brick-maker's bench, is the mould from which every brick is formed. A portion of the plastic mixture of which the bricks consist is made ready for the workman by less skilful hands, and being thrown by him with some force into the mould, it fills all the angles. The

*Manu-
factures.* upper surface is then smoothed off by a stick dipped in water drawn across the upper sides of the pattern box. *Sect. I.*

Tiles of various kinds and forms are made of finer materials, but by the same system of Moulding.

Of embossed China.—Many of the forms given to those beautiful specimens of earthen-ware which form the equipage of our breakfast and our dinner tables, are not capable of being executed in the lathe of the potter. The embossed ornaments on the edges of the plates, their polygonal shape, the fluted surface of many of the vases, would all be difficult and costly of execution by the hand; but they become easy and uniform in all their parts, when made by pressing the soft material out of which they are formed, into a hard mould. *Porcelain.*

The care and skill bestowed on the preparation of that mould are repaid by the multitude it produces. In many of the works of the China manufactory one part only of the article is moulded: the upper surface of the plate, for example, whilst the under side is figured by the lathe. In some instances the handle, or only a few ornaments, are moulded, and the body of the work is turned.

Glass seals.—The process of engraving upon gems is one requiring considerable time and skill. The seals thus produced can therefore never become common. Imitations, however, have been made of various degrees of resemblance. The colour which is given to glass is, perhaps, the most successful part of the imitation. A small cylindrical rod of coloured glass is heated in the flame of a blow-pipe, until the extremity becomes soft. The operator then pinches it between the ends of a pair of nippers, which are formed of brass, and on one side of which has been carved in relief the device intended for the seal. When care has been taken in heating the glass properly, and when the mould has been well finished, the seals thus produced are not bad imitations. By this system of Copying they are so multiplied, that at Birmingham the more ordinary kinds are to be purchased at threepence a dozen. *Glass seals.*

Square glass bottles.—The round forms which are usually given to vessels of glass are readily produced by the expansion of the air with which they are blown. It is, however, necessary in many cases to make bottles of a square form, and each capable of holding exactly the same quantity of fluid. It is also frequently desirable to have imprinted on them the name of the maker of the medicine or other liquid they are destined to contain. A mould of iron, or of copper, is provided of the required size, on the inside of which are engraved the names intended. This mould, which is used in a hot state, opens into two parts, to allow the insertion of the round, unfinished bottle, which is placed in it in a very soft state before it is removed from the end of the iron tube with which it was blown. The mould is now closed, and by blowing strongly into the bottle the glass is forced against its sides. *Square glass bottles.*

Wooden snuff-boxes.—Snuff-boxes ornamented with devices, in imitation of carved work or of rose-engine turning, are sold at a price which proves that they are only imitations. The wood, or horn, out of which they are formed, is softened by long boiling in water, and whilst in a soft state it is forced into moulds of iron, or steel, on *Ornamented wooden boxes.*

Manu-
factures.

which are carved or engraved the requisite patterns, where it remains exposed to great pressure until it is dry.

Horn-
working.

Horn knife-handles and umbrella-handles.—The property which horn possesses of becoming soft by the action of water and of heat, fits it for many useful purposes. It is pressed into moulds, and becomes embossed with figures in relief, adapted to the nature and use of the objects to which it is to be applied. If curved, it may be straightened; or if straight, it may be bent into forms which ornament or utility may require; and by the use of the mould these forms may be multiplied in endless variety.

The commoner sorts of knives, the crooked handles for umbrellas, and a multitude of other articles to which horn is applied, attest the cheapness which the Art of Copying gives to the things formed of this material.

Tortoise
shell.

Moulding tortoise shell.—The same principle is applied to things formed out of the shell of the turtle, or the land tortoise. From the greatly superior price of the raw material, this principle of Copying is, however, more rarely employed upon it; and the few carvings which are demanded, are usually performed by hand.

Tobacco
pipes.

Tobacco pipe making.—This simple Art is almost entirely one of Copying. The moulds are formed of iron, and open in the middle; the line of junction of the two parts of the mould may generally be observed running lengthwise from one end of the pipe to the other. The hole passing to the bowl is formed by thrusting a long wire through the clay whilst it is enclosed in the mould. Some of the moulds have figures, or names, sunk in the inside. This gives a corresponding figure in relief upon the finished pipe.

Embossing
calico.

Embossing upon calico.—Calicoes of one colour but embossed all over with various raised patterns, although not much worn in this Country, are in great demand in several foreign markets. This appearance is produced by passing them through a pair of rollers, on one of which is figured in intaglio the pattern to be transferred to the calico. The substance of the cloth is pressed very forcibly into the cavities thus formed, and preserves its figured appearance after considerable use.

Embossing
leather.

Embossing upon leather.—This Art of Copying from steel rollers patterns previously engraved on them, is in most respects similar to the preceding. The leather is forced into the cavities, and that part which is not opposite to any cavity is powerfully condensed between the rollers.

Swaging.

Swaging.—This is an Art of Copying practised by the smith. In order to fashion his iron and steel into the form demanded by his customers, he has small blocks of steel into which are sunk cavities of various shapes; these are called *swages*, and are generally in pairs. If he wants a round bolt, terminating in a cylindrical head of larger diameter, and having one or more projecting rims, he uses a corresponding *swaging* tool; and having heated the end of his iron rod, and thickened it by a process which is technically called *upsetting*, he places its head upon one of the parts; and whilst an assistant holds the other part, he strikes it several times with his hammer, occasionally turning the head one quarter round. The iron which was in a softened state is thus forced by the blows to assume the form of the mould into which it is impressed.

Manu-
factures.

Sect. I.

Transferring
impressions
from steel
to copper.

Engraving copper plates by pressure.—This is one of the most beautiful instances of the Art of Copying carried to an almost unlimited extent; and the delicacy with which it can be executed, and the precision with which the finest traces of the graving tool can be transferred from steel to copper, or even from hard steel to soft steel, is most unexpected. We are indebted to Mr. Perkins for most of the contrivances which have brought this Art at once almost to perfection. An engraving is first made upon soft steel, which is hardened by a peculiar process without in the least injuring its delicacy. A cylinder of soft steel, pressed with great force against the hardened steel engraving, is now made to roll slowly backward and forward over it. The soft steel cylinder receives the design, but it is in relief. This is in its turn hardened without injury; and if it be slowly rolled to and fro with strong pressure on successive plates of copper, it will imprint on a thousand of them a perfect fac-simile of the original steel engraving from which it resulted. Thus is the number of copies producible from the same design multiplied a thousand fold.

But even this is very far short of the limits to which this process may be extended. The hardened steel roller may be employed to make a few of its first impressions upon plates of *soft steel*, and these being hardened may in their turn become the parents of other rollers, each generating copper plates like the original. The possible extent to which fac-similes of an original engraving may thus be multiplied, almost confounds the imagination, and appears to be, for all practical purposes, unlimited. There are two principles which peculiarly fit this Art for rendering the forgery of Bank-notes, to prevent which Mr. Perkins proposed it, a matter of great difficulty. The first is the perfect identity of every impression with every other, so that any variation in the minutest line would at once cause detection. The other principle is, that the plates from which all the impressions are deduced may be formed by the united labours of artists most eminent in their several departments, all working at the same time; and that, as only one original of each design is necessary, the expense, however great, will be trifling, compared with the immense multitude of copies produced from it.

Gold and silver moulding.—Many of the mouldings used by jewellers consist of thin slips of metal, which have received their form by passing between steel rollers, thus taking a succession of Copies of the devices engraved upon them.

Ornamental papers.—Sheets of paper coloured or covered with gold or silver leaf, and embossed with various patterns, are used for covering books, and for many ornamental purposes. The figures upon these are produced by the same process, that of passing the sheets of paper between engraved rollers.

Embossing
ornamental
paper.

OF COPYING BY STAMPING.

This principle of Copying is extensively employed in the Arts. It is generally executed by means of large presses worked with a screw and heavy fly-wheel. The

Manu-
factures.

materials on which the Copies are impressed are most frequently metals, and the process is sometimes executed when they are hot, and in one case when the metal is in a state between solidity and fluidity.

Sect. I.

Coining.

The whole of the coins which circulate as money are produced by this mode of Copying. The screw-presses are either worked by manual labour, or by water, or steam power. The Mint which was sent a few years since to Calcutta was capable of coining 200,000 pieces a day.

Medals, which usually have their figures in higher relief than coins, are produced by similar means; but a single blow is rarely sufficient to bring them to perfection, and the compression of the metal which arises from the first blow renders it too hard to receive many subsequent blows without injury to the die. It is therefore, after being struck, removed to a furnace in which it is carefully heated red-hot and annealed, after which operation it is again placed between the dies, and receives additional blows. For large medals, and those on which the figures are very prominent, these processes must be repeated many times. One of the largest medals hitherto struck underwent them nearly one hundred times before it was completed.

Ornaments on military accoutrements and furniture ornaments.—These are usually made of brass, and are stamped up out of solid or sheet brass by placing it between dies, and allowing a heavy weight to drop upon the upper die from a height of from five to fifteen feet.

Buttons.

Buttons and nail-heads.—Buttons embossed with crests or other devices are produced by the same means, and some of those which are plain receive their hemispherical form from the dies in which they are struck.

The heads of several kinds of nails which are portions of spheres, or polyhedrons, are also formed by these means.

Clichée.

Of a process for Copying, called, in France, Clichée.—This curious method of Copying by stamping is applied to medals, and in some cases to forming stereotype plates. There exists a range of temperature previous to the melting point of several of the alloys of lead, tin, and antimony, in which the compound is neither solid, nor yet fluid. In this kind of pasty state it is placed in a box under a die, which descends upon it with considerable force. The blow drives the metal into the finest lines of the die, and the coldness of the latter immediately solidifies the whole mass. A quantity of the half melted metal is driven about by the blow in all directions, and is retained by the sides of the box in which the process is carried on. The work thus produced is admirable for its sharpness; but it has not the finished form of a piece just leaving the coining press. The sides are ragged, and it must be trimmed, and its thickness equalized in the lathe.

OF COPYING BY PUNCHING.

This mode of Copying consists in driving, either by a blow or by pressure, a steel punch through the substance to be cut. In some cases the object is to make repeated

Manu-
factures.

Copies of the same sized aperture, and the substance separated from the plate is rejected: in other cases it is the small pieces cut out which are the objects of the workman's labour.

Sect. I.

Punching iron plate for boilers.—The steel punch used for this purpose is from three-eighths to three-quarters of an inch in diameter, and drives out from a plate of iron a circular disc from one-quarter to five-eighths of an inch thick. Punching.

Punching tinned iron.—The ornamental patterns of open work which decorate the tinned and japanned wares in general use, are rarely punched by the workman who makes them. In London the Art of punching out these patterns in screw-presses is carried on as a separate trade, and large quantities of sheet tin are perforated for cullenders, wine-strainers, borders of waiters, and other similar purposes. The perfection and the regularity to which the Art has been carried are considerable: sheets of copper too are punched with small holes about the hundredth of an inch in diameter, in such multitudes that more of the sheet of metal is removed than remains behind, and plates of tin have been perforated with above three thousand holes in each square inch. Punching
tinned iron.

In all the remaining illustrations of the Art of Copying by punching, the part made use of is that which is punched out.

Cards for guns.—The substitution of a circular disc of thin card instead of paper for retaining in its place the charge of a fowling piece, is attended with considerable advantage. It would, however, be of little avail, unless an easy method was contrived of producing an unlimited number of cards, each exactly fitting the bore of the barrel. The small steel tool used for this purpose cuts out innumerable circles similar to its cutting end, each of which precisely fills the barrel for which it was designed. Cards for
wadding.

Ornaments of gilt paper.—The golden stars, leaves, and other devices, sold in shops for the purpose of ornamenting articles made of paper and pasteboard, and other fancy works, are cut by punches of various forms out of sheets of gilt paper. Paper orna-
ments.

Steel chains.—The chain used in connecting the main spring and fusee in watches and clocks, is composed of small pieces of sheet steel. It is of great importance that each of these pieces should be of exactly the same size. The links are of two sorts; one of them consisting of a single oblong piece of steel with two holes in it, and the other formed by connecting two of the same pieces of steel, placed parallel to each other at a short distance, by two rivets. These two kinds of links occur alternately, and the single piece, which forms one of them, has each end placed between the ends of the adjacent double pieces, with which it is connected by the rivets which pass through all three. If the double pieces had the holes for the rivets placed at unequal distances the chain would not be straight, and would, consequently, be unfit for its purpose. Steel
chains.

COPYING WITH ELONGATION.

In this species of Copying there exists but little resemblance. It is the cross section of the thing produced which is similar to the tool through which it passes. When

Manu-
factures.

the substances to be operated upon are hard, they frequently pass in succession through several holes, and it is in some cases necessary to anneal them at intervals.

Wire-
drawing.

Wire-drawing.—The metal to be converted into wire is made of a cylindrical form, and drawn forcibly through circular holes in plates of steel; at each passage it becomes smaller, and when finished its section at any point is a precise copy of the last hole through which it passed. Upon the larger kinds of wire fine lines may frequently be traced running longitudinally: these arise from a slight imperfection in the holes of the draw-plates.

For many purposes of the Arts, wire, the section of which is square or half round, is required: the same method of making it is pursued, except that the holes through which it is drawn are in such cases themselves square, or half round, or of whatever other form the wire is required to be.

A species of wire is made, the section of which resembles a star with from six to twelve rays, this is called pinion wire, and is used by the clock-makers. They file away all the rays from a short piece, except from about half an inch near one end: this becomes a pinion for a clock, and the leaves having passed through the draw-plate are already burnished and finished.

Tube
drawing.

Tube drawing.—The Art of forming tubes of uniform diameter is nearly similar in its mode of execution to wire-drawing. After the sheet-brass has been bent round and soldered, if the outside diameter is that which is required to be uniform, it is drawn through a succession of holes, as in wire-drawing. If the inside diameter is to be uniform, a succession of steel cylinders, called *triblets*, are drawn through the brass tube.

In making tubes for telescopes it is necessary that both the inside and outside should be uniform. A steel *triblet* is passed into the tube, which is then drawn through a succession of holes, until the outside diameter is reduced to the required size. The metal of which the tube is formed, is condensed between the holes and the steel cylinder within it; and when the latter is withdrawn the internal surface appears polished. The brass tube is considerably extended by this process, sometimes even to double its first length.

Leaden
pipes.

Leaden pipes for the conveyance of water were formerly made by casting; but it has been found that they can be made both cheaper and better by drawing them through holes in the manner of wire. A cylinder of lead of five or six inches in diameter, and about two feet long, is cast with a small hole through its axis, and an iron *triblet* fifteen feet in length is forced into the hole. It is then drawn through a series of holes until the lead has extended from one end to the other of the *triblet*, and is of the proper thickness in proportion to the size of the pipe.

Iron rolling.—When cylinders of iron, of greater thickness than wire, are required, they are formed by passing wrought iron between rollers each of which has sunk in it a semicylindrical groove; and as such rollers rarely touch accurately in iron so manufactured, a longitudinal line will usually be observed. Bar iron is manufactured in this way into all the various shapes of round, square, half-round, oval, &c. in which it occurs

<sup>Manu-
factures.</sup> in commerce. It is sometimes required that the iron thus produced shall not be of ^{Sect. I.} uniform thickness throughout. This is the case in rolling iron for rail-roads, for which <sup>Iron
rail-roads.</sup> purpose greater depth is required towards the middle of the rail which is at the greatest distance from the supports. This is accomplished by cutting the groove in the rollers deeper at those parts wherein additional strength is required; so that the hollow which surrounds the roller would, if it could be unwound, be a mould of the shape the iron is intended to fit.

Vermicelli.—The various forms into which this paste is made are given by forcing ^{Pastry} it through holes in tin plate. It passes through them, and appears on the other side in long strings. The cook and the confectioner make use of the same method; the former in preparing butter and ornamental pastry for the table, the latter in forming the cylindrical lozenges of various composition.

OF COPYING WITH ALTERED DIMENSIONS.

Of the pentagraph.—This mode of Copying is chiefly used for Drawings or Maps: the instrument is simple, and, although usually employed in reducing, is capable of increasing the size of the Copy produced.

An automaton figure, which drew profiles of its visitors, and which was exhibited in London a short time since, was regulated by a mechanism on this principle. <sup>Automaton
Profile
drawer.</sup>

A small aperture in the wall, opposite the seat in which the person is placed whose Profile is taken, conceals a *camera lucida*. If an assistant moves the point, connected by a pentagraph with the hand of the automaton, over the outline of the head, a corresponding profile is traced by the figure.

Rose engine turning.—This elegant Art depends in a great measure on Copying. The rosettes which are placed on the mandril oblige the cutting tool to trace out the same <sup>Engine
turning.</sup> pattern on the work, and the distance of the tool from the centre being usually less than the radius of the rosette, causes the copy to be much diminished.

Copying dies.—A lathe has been long known in France, and recently been used at the English Mint for copying dies. A blunt point is carried by a very slow spiral movement successively over every part of the die to be copied, and is pressed by a weight into all the cavities; while a cutting point connected with it by the machine traverses the face of a piece of soft steel, in which it cuts on the same or on a diminished scale, the device on the original die. The degree of excellence of the copy increases in proportion as it is smaller than the original. The die of a crown piece will furnish by copy a very tolerable die for a sixpence. But the chief use to be expected from this lathe is to prepare all the coarser parts, and leave only the finer and more expressive lines for the skill and genius of the artist. ^{Die copying}

An instrument not very dissimilar in principle to this was proposed for the purpose of making shoe lasts. A pattern last of a shoe for the right foot was placed in one part of the apparatus; and, when the machine was moved, two pieces of wood, placed in <sup>Shoe last
making.</sup>

Manu-
factures.

another part which had been previously adjusted by screws, were cut into lasts greater or less than the original, as was desired; and although the pattern was for the right foot one of the lasts was for the left.

Screw
cutting.

Screw cutting.—When this operation is performed in the lathe by means of a screw upon the mandril, it is essentially an Art of Copying, but it is only the number of threads in a given length which is Copied; the form of the teeth, and length as well as the diameter of the screw to be cut, are entirely independent of those from which the Copy is made. There is another method of cutting screws in a lathe by means of one pattern screw, which, being connected by wheels with the mandril, guides the cutting point. In this process, unless the time of revolution of the mandril is the same as that of the screw which guides the cutting point, the number of threads in a given length will be different. If the mandril move quickest, the screw which is produced will be finer than the original; if it move slower, the Copy will be more coarse than the original. The screw thus generated may be finer or coarser,—it may be larger or smaller in diameter,—it may have the same number of threads or a greater number than that from which it is Copied; yet all the defects which exist in the original will be accurately transmitted, under the modified circumstances, to every individual generated from it.

The Art of turning might perhaps itself be classed amongst the Arts of Copying. All work which is executed on a mandril partakes in some measure of the irregularities of that mandril, and the perfect circularity of section which ought to exist at every part, can only be ensured by an equal accuracy in the mandril and its collar.

Impressions
of various
size from the
same copper
plate.

Some very singular specimens of an Art of Copying, not yet made public, were brought from Paris a few years since. A watch-maker in that city, of the name of Gonord, had contrived a method by which he could take from the same copper plate impressions of different sizes, either larger or smaller than the original design. Four impressions of an Eagle were examined in the presence of the writer of this paper, by a late artist equally distinguished for his skill and for the many mechanical contrivances with which he enriched his Art. The largest was four times the superficial size of the smallest, and no lines were detected in one which had not corresponding lines in the others. There appeared to be a difference in the quantity of ink, but none in the traces of the engraving. The processes by which this singular operation was executed have not been published, but two conjectures were formed at the time which merit notice. It was supposed that the artist was in possession of some method of transferring the ink from the lines of a copper plate to the surface of some viscous fluid, and also of retransferring the impression from the fluid to paper. If this could be accomplished, the Print would be of exactly the same size as the copper from which it was derived; but if the viscous fluid were contained in a vessel having the form of an inverted cone with a small aperture at the bottom, the liquid might be lowered or raised in the vessel by gradual abstraction or addition through the apex of the cone; in this case, the surface to which the printing ink adhered would diminish or enlarge, and in this altered state the impression might be retransferred to paper. It must be admitted, that this conjectural expla-

Explanation

Manu-
factures.

Sect. I.

nation is not without considerable difficulties, for although the converse operation of taking an impression from a liquid surface has a parallel in the Art of marbling paper, the possibility of transferring the ink from the copper to the fluid requires to be proved.

Another and more plausible explanation is founded on the elastic nature of the compound of glue and treacle, a substance already in use in transferring engravings to earthenware. It is conjectured, that an impression from the copper plate is taken upon a large sheet of this composition; that this sheet is then stretched in both directions, and that the ink thus expanded is transferred to paper. If the Copy is required to be smaller than the original, the elastic substance must first be stretched, and then receive the impression from the copper plate: on removing the tension it will contract, and thus reduce the size of the design. It is possible that one transfer may not in all cases suffice, as the extensibility of the composition of glue and treacle, although considerable, is still limited.

Second
explanation.

Perhaps sheets of Indian rubber of uniform texture and thickness may be found to answer better than this composition. As it would require considerable time to produce impressions in this manner, and there might arise some difficulty in making them all of precisely the same size, the process might be rendered more certain and expeditious, by performing that part of the operation which depends on the enlargement or diminution of the design only once; and, instead of printing from the soft substance, transferring the design from it to stone: thus a considerable portion of the work would be reduced to an Art already well known, that of Lithography.

We shall terminate this enumeration, which is far from complete, of the Arts in which Copying is the foundation, with an example which has long been under the eye of our readers, although few, perhaps, are aware of the great extent of repeated Copying of which these very pages are the subject.

Instance
of multi-
plied
Copying.

1. They are Copied by Printing from stereotype plates.
2. These stereotype plates are Copied, by the Art of casting, from moulds formed of plaster of Paris.
3. Those moulds are themselves Copied by casting the plaster in a liquid state upon the movable type set up by the compositor.

[It is here that the union of the intellectual and the mechanical departments takes place. Through how many stages of repeated Copying the matter which is here delivered to the reader may have travelled, we shall leave involved in a veil which his sagacity may penetrate; merely observing, that in numerous instances the mental far outruns the mechanical Copyist.]

4. These movable types, the obedient messengers of the most opposite thoughts, the most conflicting theories, are themselves Copies, by casting from moulds of copper called *matrices*.

5. The lower part of those *matrices* bearing the impressions of the letter or character intended, are Copies by punching from steel punches on which the same character exists in relief.

Manu-
factures.

Sect. I.

6. These steel punches are not themselves entirely exempted from the great principle of Art. Many of the cavities which exist in them, such as those in the middle of the punches for the letters *a, b, d, e, g, &c.* are produced from other steel punches in which these parts are in relief.

We have thus traced through six successive stages of Copying the mechanical Art of Printing from stereotype plates. In this, as in every other department of Manufacture, the principle of Copying contributes to the uniformity and the cheapness of the work produced.

CHAPTER II.

OF THE ECONOMICAL PRINCIPLES OF MANUFACTURES.

INTRODUCTION.

*Manu-
factures.* To produce any article of consumption in a perfect form is the first object of every person who attempts to make it; but in order to secure to himself the greatest and most permanent profit, he must endeavour by every means in his power to render the new luxury or want, which he has created, cheap to those who consume it.

The number of his purchasers will, in some measure, secure him from the caprices of fashion, whilst it furnishes a far larger amount of profit, although the contribution of each individual is diminished.

If, therefore, he wish to become a Manufacturer, he must attend to other principles besides those mechanical ones on which the successful execution of his work depends; he must carefully arrange the whole system of his factory in such a manner, that the article he sells to the Public may be produced at as small cost as possible.

Should he not be actuated by such remote motives, he will in every highly civilized Country be compelled, by the powerful stimulus of competition, to attend to these principles of the domestic economy of Manufactures. At every reduction in price of the commodity he makes, he will be driven to seek compensation in a saving of expense in some of the processes, and his ingenuity will be sharpened in this inquiry by the hope of being able in his turn to undersell his rivals.

The improvements thus engendered remain for a short time enriching those from whose ingenuity they derived their origin; but when a sufficient experience has shown their value, they become generally adopted, until these in their turn are superseded by other more economical methods.

The *economical principles* which regulate the application of Machinery, and which govern the interior of all our great factories, are quite as essential to the prosperity of a great commercial Country, as are those Mechanical ones the operations of which we have attempted to illustrate in the preceding Chapter.

ON THE DIVISION OF LABOUR.

One and perhaps the most important principle on which the economy of a Manufacture depends, is the division of labour amongst the operatives who work at it. The first application of this principle must have been made in a very early stage of Society, and it must soon have been apparent, that more comforts and conveniences could be acquired by one man restricting his occupation to the art of making bows, another to that of building houses, a third boats, and so on.

This division of labour into Trades was not, however, the result of an opinion, that the <sup>Division of
labour.</sup> general riches of the community would be increased by such an arrangement; but it

Manu-
factures.

arose from the circumstance of each individual so employed discovering that he himself could thus make a greater profit of his labour than by pursuing more varied occupations.

Sect. 1.

Society must have made considerable advances before that principle could have been carried into the workshop, for it is only in Countries which have attained a high degree of civilization, and in articles in which there is a great competition amongst the producers, that the most perfect system of the division of labour is to be observed.

The principles on which the advantages of this system depend, have been much the subject of discussion amongst writers on Political Economy, but the relative importance of their influence does not appear in all cases to have been estimated with sufficient precision.

It is our intention in the first instance to state shortly those principles, and then to point out the omissions which have been made by those who have treated the subject, and more especially by one of our own authors of the highest authority.

Time con-
sumed in
learning.

1. Of the time required for learning.

It will readily be admitted, that the portion of time occupied in the acquisition of any Art will depend on the difficulty of its execution, and that the greater the number of distinct processes, the longer will be the time which the apprentice must employ in acquiring it. Five or seven years have been adopted in a great many trades as the time considered requisite for a lad to acquire a sufficient knowledge of an Art, and to repay by his labour, during the latter portion of his time, the expense incurred by his master at its commencement. If, however, instead of learning all the several processes of making a needle, for instance, his attention is confined to one operation, a very small portion of his time will be consumed unprofitably at the commencement, and the whole of the rest of it will be beneficial to his master; and if there be any competition amongst the masters, the apprentice will be able to make better terms and diminish the period of his servitude. Again, the facility of acquiring skill in a single process, and the early period of life at which it can be made a source of profit, will induce a greater number of parents to bring up their children to it; and from this circumstance also, the number of workmen being increased, the wages will soon fall.

Material de-
stroyed in
learning.

A certain quantity of material will be consumed unprofitably or spoiled by every person who learns an Art, and as he applies himself to each new process, he will waste a certain quantity of the raw material, or of the partly manufactured commodity. But whether one man in succession commits this waste in acquiring each process, or many persons separately learn the several processes, the quantity of waste will remain the same; therefore in this view of the subject the division of labour will neither increase nor diminish the price of production.

Loss of time
in changing
occupation.

2. Another reason of the advantage resulting from the division of labour is, that *time is always lost in changing from one occupation to another.*

When the human hand or the human head has been for some time occupied in any kind of work, it cannot instantly change its employment with full effect. The muscles of the limbs employed have acquired a flexibility during their exertion, and those to be put in action a stiffness during rest, which renders any change in the commencement

^{Manu-}slow and unequal. A similar result seems to take place in any change of mental ex-
^{factures.}ertion; the attention bestowed on the new subject is not so perfect at the first com-
 mencement as it becomes after some exercise. Long habit also produces in the muscles
 exercised a capacity for enduring fatigue to a much greater degree than they could
 support under other circumstances.

Sect. I.

Another cause of the loss of time in changing from one operation to another, arises
 from the employment of different tools in the two processes. If these tools are simple
 in their nature, and the change is not frequently repeated, the loss of time is not con-
 siderable; but in many processes of the Arts there are tools of great delicacy, requiring
 accurate adjustment whenever they are used. In many cases the time employed in
 adjusting bears a large proportion to that employed in using the tool. The sliding
 rest, the dividing and the drilling engine, are of this kind, and hence in Manufactories
 of sufficient extent, it is found to be good economy to keep one Machine constantly
 employed in one kind of work; one lathe, for example, having a screw motion to its
 sliding rest along the whole length of its bed, is kept constantly making cylinders;
 another, having a motion for rendering uniform the velocity of the work at the point
 at which it passes the tool, is kept for facing surfaces; whilst a third is constantly
 employed in cutting wheels.

In adjust-
ment of
tools.

3. Skill acquired by frequent repetition of the same processes.

The constant repetition of the same process necessarily produces in the workman a
 degree of excellence and rapidity in his particular department, which is never possessed
 by one who is obliged himself to execute many different processes. This rapidity is
 still further increased from the circumstance of most of the operations in factories, where
 the division of labour is carried to a considerable extent, being paid for as piece-work.
 It is difficult to estimate the numerical effect of this cause upon production. In nail-
 making, Adam Smith has stated that it is almost three to one; or, in other words, that
 a smith accustomed to make nails, but whose whole business has not been that of a
 nailer, can make only from eight hundred to a thousand per day; whilst a lad who had
 never exercised any other trade, can make upwards of two thousand three hundred a day.

Skill ac-
quired by
repetition.

In different trades the economy of production arising from this cause will neces-
 sarily be different. The case of nail-making is perhaps rather an extreme one. It
 must, however, be observed that in one sense, this is not a permanent cause, for although
 it acts at the commencement of an establishment, yet every month adds to the skill of
 the workman, and at the end of a certain time he will not be very far behind those
 who have practised only the peculiar branch.

4. The division of labour suggests contrivances for tools and Machinery to execute its processes.

Suggests
tools.

When each process by which any article is produced is the sole occupation of one
 individual, his whole attention being devoted to a very limited and simple operation, any
 improvement in the form of his tools, or in the mode of using them, is much more likely
 to occur to his mind, than if it were distracted by a greater variety of circumstances. Such
 an improvement in the tool is generally the first step towards a Machine. If a piece of

Manu-
factures.

metal is to be cut in a lathe, for example, there is one angle at which the cutting tool must be held to ensure the cleanest cut ; it is quite natural that the idea of fixing the tool at that angle should present itself to an intelligent workman. The necessity of moving the tool slowly, and in a direction parallel to itself, would suggest the use of a screw, and thus arises the sliding rest. It was probably the idea of mounting a chisel in a frame, to prevent its cutting too deeply, which gave rise to the common carpenter's plane. In other instances a blow from a hammer is employed, and experience teaches the proper force required. The transition from the hammer held in the hand to one mounted upon an axis, and lifted regularly to a certain height by the foot, requires perhaps a greater degree of invention. Yet it is not difficult to perceive that if the hammer always falls from the same height its effect must be always the same.

Sect. I.

Union of
tools makes
masses.

When each process has been reduced to the use of some simple tool, the union of all these actuated by one moving power constitutes a Machine. In contriving tools and processes, the operative workmen are perhaps most successful, but it requires far other habits to combine into one Machine these scattered Arts. A previous education as a workman in the peculiar Trade is undoubtedly a valuable preliminary, but to do it with any reasonable expectation of success, an extensive knowledge of Machinery, and the power of making mechanical drawings are essentially requisite. Such accomplishments are now much more frequent than they were formerly, and their absence was perhaps one of the causes of the multitude of failures in the early history of many of our Manufactures.

Such are the principles usually assigned as the cause of the advantages resulting from the division of labour. As in our view of the question a very prominent cause has been altogether unnoticed, we shall give them in the words of Adam Smith.

“ The great increase in the quantity of work which in consequence of the division of labour the same number of people are capable of performing, is owing to three different circumstances : first, to the increase of dexterity in every particular workman ; secondly, to the saving of time, which is commonly lost in passing from one species of work to another ; and, lastly, to the invention of a great number of Machines which facilitate and abridge labour, and enable one man to do the work of many.”

Now although these causes are all important ones, and have each their influence in the result, yet it appears to us that any explanation of the cheapness of Manufactured articles as resulting from the division of labour, would be incomplete if the following principle were omitted to be stated.

Division of
labour en-
ables mas-
ters to pur-
chase pre-
cisely that
portion of
skill re-
quired.

That the master Manufacturer, by dividing the work to be executed into different processes, each requiring different degrees of skill and of force, can purchase exactly that precise quantity which is necessary for each process ; whereas, if the whole work were executed by one workman, it is evident that that workman must possess sufficient skill to perform the*

* The writer of this Essay derived his first knowledge of this principle from a personal examination of a variety of Manufactories and Workshops devoted to different purposes ; but he has since found that it has been distinctly stated in the Work of Gioja, *Nuovo Prospetto delle Scienze Economiche*, 6 tom. 4to. Milano, 1815, tom. i. capo iv.

Manu- *most difficult, and sufficient strength to execute the most laborious, of the operations into which* Sect. I.
factures. *the Art is divided.*

As the clear apprehension of this principle, upon which so much of the economy arising from the division of labour depends, is of considerable importance, it may be desirable to illustrate it by pointing out its precise and numerical application in some specific Manufacture. The art of making needles is perhaps that which we should have selected as comprehending a very large number of processes remarkably different in their nature; but the less difficult art of pin-making, referred to by Adam Smith, has some claim to our attention from its having been used as the earliest illustration of the subject; and we are confirmed in the choice by the circumstance of possessing a very accurate and minute description of that Art as practised in France above half a century ago.

In the Manufacture of pins in England the following processes are employed.

1. The brass wire used for making pins is purchased by the Manufacturer in coils of about twenty-two inches in diameter, each weighing about thirty-six pounds. These coils are wound off into smaller ones of about six inches diameter, and between one and two pounds weight. Example.
Pinmaking.

The diameter of this wire is now reduced by drawing it repeatedly through holes in steel plates until it becomes of the size required for the sort of pins intended to be made; during the process of drawing the wire through these holes it becomes hardened, and it is necessary to anneal it in order to prevent its breaking, and to enable it to be still further reduced; it is annealed two or three times according to the diminution of diameter required.

These coils are soaked in sulphuric acid largely diluted with water, in order to clean them, and are then beaten on stone, for the purpose of removing any oxidated coating which may adhere to them.

This process is usually performed by men, who draw and clean from thirty to thirty-six pounds a day. They are paid at the rate of five farthings per pound, and generally earn about 3s. 6d. per day.

M. Perronet made some experiments on the extension of the wire at each hole. He took a piece of Swedish brass wire, and found

	Feet.	Inches.
Its length to be	3	8
After passing the first hole	5	5
———— second hole	7	2
———— third hole	7	8
It was now annealed, and		
After passing the fourth hole	10	8
———— fifth hole	13	1
———— sixth hole	16	8
And after passing through six others	144	0

The holes through which the wire was drawn were not in this experiment of regularly decreasing diameter; and it is extremely difficult to make such holes, and still more to preserve them in their original dimensions.

2. The coil of wire now passes into the hands of a woman, assisted by a boy or girl.

Manu-
factures.
Straighten-
ing the wire.

A few nails, not quite in a line, are fixed into one end of a wooden table; the end of the wire is passed alternately between these nails, and is then pulled to the other end of the table about twenty feet in length. The object of this process is to straighten the wire which had acquired an uniform curvature in the small coils into which it had been wound. The length thus straightened is cut off, and the remainder of the coil is drawn into similar lengths. Sect. I.

About seven nails or pins are employed in straightening the wire, and the adjustment is a matter of some nicety. It seems, that by passing the wire between the first three nails or pins a bend is produced in an opposite direction to that which the wire had in the coil; this bend is again reduced to another of larger curvature in the first direction, and so on until the curvature of the last is so large that it may be confounded with a straight line.

A man next takes a parcel, about 300 of these pieces, and putting them into a gauge cuts off from one end, by means of a pair of shears moved by his foot, about 300 pieces, each equal in length to rather more than six pins. He continues this operation until the whole parcel is reduced into similar pieces.

Sharpening
points.

The next step is to sharpen the ends of these pieces: for this purpose the operator sits before a steel mill, which is kept rapidly revolving; and taking up a parcel between the finger and thumb of each hand, he passes the ends before the mill, taking care with his fingers and thumbs to make each wire slowly revolve. The mill consists of a cylinder about six inches in diameter, and two and a half inches broad, faced with steel, which is cut in the manner of a file. Another similar one is fixed on the same axis at a few inches distant; the file on the edge of this is of a finer kind, and is used for finishing off the points. Having thus pointed all the pieces at one end he reverses them, and performs the same process upon the other ends. This process requires considerable skill, but it is not unhealthy; whilst the similar process in needle-making is remarkably destructive of health.

These pieces, which are now pointed at both ends, are placed in gauges, and the pointed ends are cut off by means of shears to the proper length of which the pins are to be made. They are now equal to about four pins in length, and are again pointed at each end, and their ends again cut off. This process is repeated a third time, and the small portion of wire in the middle is thrown amongst the waste, to be melted up with the dust arising from the sharpening.

It is usual for a man, his wife, and a child, to join in performing these processes; and they are paid at the rate of five farthings per pound. They can do from thirty-four to thirty-six and a half pounds per day, and gain from 6s. 6d. to 7s., which may be apportioned thus; 5s. 6d. the man, 1s the woman, 6d. to the boy or girl.

Making the
heads.

3. The next process is making the heads. For this purpose a boy takes a piece of wire, of the same diameter as the pin to be headed, which he fixes on an axis that can be made to revolve rapidly by means of a wheel and strap connected with it. This wire is called the mould. He then takes a smaller wire, which having passed through an eye in a small tool held in his left hand, he fixes close to the bottom of the mould. The

Manu-
factures.

Sect. I.

mould is now made to revolve rapidly by means of the right hand, and the smaller wire coils round it until it has covered the whole length of the mould. The boy now cuts the end of the spiral connected with the foot of the mould, and draws it off.

When a quantity of heading is thus made, a man takes from thirteen to twenty of these spirals in his left hand between his thumb and three outer fingers; these he places in such a manner that two turns of the spiral shall be beyond the upper edge of a pair of shears, and with the fore finger of the same hand he feels these two projecting turns. With his right hand he closes the shears, and the two turns of the spiral being cut off drop into a basin. The position of the fore finger prevents the heads from flying about when cut off.

The workmen who cut the heads are usually paid at the rate of $2\frac{1}{4}d.$ to $3d.$ per pound for large, but a higher price is given for the smaller heading. Out of this they pay the boy who spins the spiral; he receives from $4d.$ to $6d.$ per day. A good workman can cut from 6 pounds to about 30 pounds of heading per day, according to its size.

4. The process of fixing on the head to the body of the pin is usually executed by women and children. Each operator sits before a small steel stake, having a cavity, into which one-half of the intended head will fit; immediately above is a steel die, having a corresponding cavity for the other half of the head: this latter die can be raised by a pedal moved by the foot. The cavities in the centre of these dies are connected with the edge by a small groove, to admit of the body of the pin, which is thus prevented from being flattened by the blow of the die. The operator with his left hand dips the pointed end of the body of a pin into a tray of heads, and having passed the point through one of them, he carries it along to the other end with the fore finger. He now takes the pin in the right hand, and places the head in the cavity of the stake, and lifting the die with his foot allows it to fall on the head. This blow tightens the head on the shank, which is then turned round, and the head receives three or four blows on different parts of its circumference. The women and children who fix the heads are paid at the rate of $1s. 6d.$ for every 20,000. A skilful operator can with great exertion do 20,000 per day, but from 10,000 to 15,000 is the usual quantity: children head a much smaller, number varying of course with the degree of their skill.

Fixing the
heads.

The weight of the hammer is from seven to ten pounds, and it falls through a very small space, perhaps from one to two inches. About one per cent. are spoiled in the process; these are picked out afterwards by women, and are reserved with the waste from other processes for the melting pot. The form of the dies in which the heads are struck is varied according to the fashion of the time, but the repeated blows to which it is subject renders it necessary that it should be repaired after it has been used for about thirty pounds of pins.

5. The pins are now fit to be tinned, a process which is usually executed by a man assisted by his wife, or by a lad.

Tinning the
pins.

The quantity of pins operated upon at this stage is usually fifty-six pounds. They are first placed in a pickle in order to remove any grease or dirt from their surface, and also to render that surface rough, which facilitates the adherence of the tin with which they

Manu-
factures.

are to be covered. They are then placed in a boiler full of a solution of tartar in water in which they are mixed with a quantity of tin in small grains. They are usually kept boiling for about two hours and a half, and are then removed into a tub of water into which some bran has been thrown; this is for the purpose of washing them. They are then taken out, and being placed in wooden trays are well shaken in dry bran; this removes any water adhering to them, and by giving the wooden tray a peculiar kind of motion, the pins are thrown up, and the bran gradually flies off, and leaves them behind in the tray.

Sect. I.

The man who pickles and tins the pins usually gets one penny per pound for the work, and employs himself during the boiling of one batch of pins with drying those previously tinned. He can earn about 9s. per day; but out of this he pays about three for his assistant.

Papering
the pins.

6. The arranging of pins side by side in paper is generally performed by women. The pins come from the last process in wooden bowls, with the points projecting in all directions. A woman takes up some and places them on the teeth of a comb, whilst, by a few shakes, some of the pins fall back into the bowl, and the rest, being caught by their heads, are detained between the teeth of the comb. Having thus arranged them in a parallel direction, she fixes the requisite number between two pieces of iron, having twenty-five small grooves, at equal distances, and having previously doubled the paper, she presses it against the points of the pins until they have passed through the two folds which detain them. The pins are then relieved from the tool, and the process repeated. A woman gains about 1s. 6d. per day by papering, but children are sometimes employed, who earn from 6d. per day, and upwards.

Having thus described the various processes without entering into the minuter details, and having stated the usual cost of each, it will be convenient to present a Tabular view of the time occupied by each process, and its cost, as well as of the sums which can be earned by the operative who devotes himself solely to each process. As the rate of wages is itself fluctuating, and as the prices paid and quantities executed have been given between certain limits, it is not to be expected that this Table can represent with the minutest accuracy the cost of each part, nor even that it shall accord perfectly with the prices above given; but it has been drawn up with some care, and will be quite sufficient for that general view and for those reasonings which it is meant to illustrate. We shall annex a Table nearly similar, which we have deduced from statements of M. Perronet, respecting the Art of pin-making in France above seventy years ago.

English Manufacture.

Pins, Elevens, 5546 weigh one pound; one doz. = 6932 pins weigh 20 ounces, and require six ounces of paper.

Name of the process.	Operative.	Time employed in making 1 pound of pins.	Cost of making one pound of pins.	Operative usually earns per day.		Price of making each part of a single pin in millionths of a penny.	Sect. I. Cost of each process in English pins.
				s.	d.		
1. Drawing Wire.....	Man	HOURS. .3636	PENCE. 1.2500	3	3	225	
	{ Man	.3000	1.7750	5	3	319	
2. Cutting and pointing	{ Woman	.3000	.2840	1	0	51	
	{ Girl	.3000	.1420	0	6	26	
3. Twisting the heading and cutting	{ Boy	.0400	.0147	0	4½	3	
	{ Man	.0400	.2103	5	4½	38	
4. Rivetting the heads.....	Woman	4.0000	5.0000	1	3	901	
5. Whitening.....	{ Man	.1071	.6666	6	0	121	
	{ Woman	.1071	.3333	3	0	60	
6. Papering.....	Woman	2.1314	3.1973	1	6	576	
		7.6892	12.8732			2320	

Number of persons employed :—Men, 4 ; Women, 4 ; Children, 2. Total 10.

French Manufacture.

Cost of 12,000 pins, No. 6, each being .8 English inches in length, with the cost of each operation, deduced from the observations and statement of M. Perronet, as they were manufactured in France about 1760.

Name of the process.	Time of making 12,000 pins.	Cost of making 12,000 pins.	Operative usually earns per day.	Expense of tools and materials.	Cost of each process in French pins.
	HOURS.	PENCE.	PENCE.	PENCE.	
1. Wire .....	....	....	....	24.75	
{ Straightening and cutting	1.2	.5	4.5		
{ Coarse pointing.....	1.2	.625	10.0		
{ Turning wheel*.....	1.2	.875	7.0		
2. { Fine pointing	.8	.5	9.375		
{ Turning wheel.....	1.2	.5	4.75		
{ Cutting off pointed ends..	.6	.375	7.5		
3. { Turning spiral.....	.5	.125	3.0		
{ Cutting off heads.....	.8	.375	5.625		
Fuel to anneal ditto ....	....	....	....	125	
4. Rivetting heads.....	12.0	.333	4.25		
Tartar for cleaning .....	....	....	....	5	
Tartar for Whitening ...	....	....	....	.5	
6. Papering	4.8	.5	2.0		
Paper.....	....	....	....	1.0	
Wear of tools.....	....	....	....	2.0	
	24.3	4.708			

* The expense of turning the wheel appears to have arisen from the person so occupied being sufficiently employed only half his time, whilst the pointer went to another manufactory.

Manu-
factures.

From an examination of the first of these Tables it appears that the wages earned by the operatives vary from $4\frac{1}{2}d.$ per day up to $6s.$, and consequently the skill which is required for their respective employments will be measured by those sums. Now it is evident that if one person is required to make the whole pound of pins, he must have skill enough to earn about $5s. 3d.$ a day whilst he is pointing or cutting off the heads, and $6s.$ when he is whitening the pins; which three operations together would occupy little more than the seventeenth part of his time. It is also apparent, that during more than one-half of his time he must be earning only $1s. 3d.$ per day in putting on the heads, although his skill, if properly employed, would, in the same time, produce nearly five times as much.

Sect. I.

It appears from the analysis we have given of the Art of pin-making, that it occupies rather more than seven hours and a half of time for ten different individuals working in succession on the same material to convert it into a pound of pins, and that the expense of their labour, each being paid in the joint ratio of his skill and the time he is employed, amounts to nearly $1s. 1d.$ Now if we were to employ the man who whitens the pins, and who earns $6s.$ a day, even supposing that he could make the pound of pins in an equally short time, yet we must pay him for his time 46.14 pence, or nearly $3s. 10d.$ *The pins would therefore cost in making three times and three quarters as much as they now do by the application of the division of labour.*

The higher the skill required of the workman in any one process of a Manufacture, and the smaller the time during which it is employed, so much the greater will be the advantage of separating that process from the rest and devoting one person's attention entirely to it. Had we selected the Art of needle-making as our illustration, the economy arising from the division of labour would have been still larger, for the process of tempering the needles requires great skill, attention, and experience, and although from three to four thousand are tempered at once, the workman is paid a very high rate of wages. In another process of the same Art, dry-pointing, which is also executed with great rapidity, the wages earned by the workman reach from $7s.$ to $12s.$, $15s.$, and even, in some instances, to $20s.$ a day, whilst other processes in the same Art are carried on by children paid at the rate of $6d.$ per day.

Pin-making
Machine.

Before we offer those further reflections which the preceding analysis suggests, it may be convenient to place before the reader a brief description of a Machine for making pins invented by an American. It is highly ingenious in point of contrivance, and, in respect to its economical principles, will furnish a strong and interesting contrast with the Manufacture of pins by the human hand.

In this Machine, a coil of brass wire being placed on an axis, one end of this wire is drawn by a pair of rollers through a small hole in a plate of steel, and is held there by a forceps.

As soon as the Machine is put in action—

1. The forceps draws the wire on to a distance equal in length to one pin. A cutting edge of steel then descends close to the hole through which the wire entered and severs a piece equal in length to one pin.

Manu-
factures.

Sect. I.

2. The forceps holding this wire moves on until it brings the wire into the centre of a chuck fixed in a small lathe which opens to receive it. Whilst the forceps returns to fetch another piece of wire, the lathe revolves rapidly and grinds the projecting end of the wire upon a steel mill which advances towards it.

3. After this first or coarse pointing the lathe stops, and another forceps takes hold of the half-pointed pin (which is instantly released by the opening of the chuck) and conveys it to a similar chuck of another lathe which receives it and finishes the pointing on a finer steel mill.

4. This mill again stops and another forceps removes the pointed pin into a pair of strong steel clams, having a small groove in them by which they hold the pin very firmly. The end of this groove, which terminates at that edge of the steel clams which is intended to form the head of the pin, is made conical. A small round steel punch is now driven forcibly against the end of the wire thus clamped, and the head of the pin is partially formed by compressing the wire into the conical cavity.

5. Another pair of forceps now removes the pin to another pair of clams, and the head of the pin is completed by a blow from a second punch, the end of which is slightly concave.

Each pair of forceps returns as soon as it has delivered its burden, and thus there are always five pieces of wire at the same moment in different stages of advance towards a finished pin. The pins so formed are received in a tray, and whitened and papered in the usual manner. About sixty pins can thus be made by this Machine in one minute, but each process occupies exactly the same quantity of time in performing.

In order to judge of the value of such a Machine compared with hand labour, it would be necessary to know—1. to what defects pins so made are liable; 2. what advantages they possess over those made in the usual way; 3. what is the prime cost of a Machine for making them; 4. what is the expense of keeping it in repair; 5. what is the expense of moving it and attending to it.

Comparison
with pins
made by
hand.

Pins made by the Machine are more likely to bend, because as the head is punched up out of the solid wire, it ought to be in a soft state to admit of this process.

Pins made by the Machine are better than common ones, because they are not subject to losing their heads.

With respect to the prime cost of a Machine, it would be very much reduced if numbers should be required.

With regard to its wear and tear, experience only can decide the question; but it may be remarked, that the steel clams or dies in which the heads are punched up, will wear quickly unless the wire has been softened by annealing, and that if it has been softened the bodies of the pins will bend too readily. Such an inconvenience might be remedied, either by making the Machine spin the heads and fix them on, or by annealing only that end of the wire which is to become the head of the pin; but this would cause a delay between the operations, since the brass is too brittle when heated to bear a blow without crumbling.

On comparing the time occupied by the Machine with that stated in the analysis, we

Manu-
factures.

Sect. I.

find, except in the process of heading, if time alone is considered, that the human hand is more rapid. Three thousand six hundred pins are pointed by the Machine in one hour, whilst a man can point fifteen thousand six hundred in the same time. But in the process of heading the rapidity of the Machine is two and a half times that of the human hand.

It must, however, be observed, that the process of grinding does not require the application of force to the Machine equal to that of one man, for all the processes we have described are executed at once by the Machine, and one labourer can easily work it.

Such an
analysis
points out
the proper
direction of
improve-
ment.

One of the first advantages which suggests itself as likely to arise from a correct analysis of the expense of the several processes of any Manufacture, is the indication which it furnishes of the course in which improvement should be directed. If any method should be contrived of diminishing by one-fourth the time required for fixing on the heads of the pins, the expense of making them would be reduced about thirteen per cent., whilst a reduction of one-half the time employed in spinning the coil of wire out of which the heads are cut, would scarcely make any sensible difference in the cost of the Manufacture of the whole article. It is therefore obvious, that the attention would be much more advantageously directed to shortening the former than the latter process.

Division of
labour ap-
plied to Mind.

We have already alluded to a circumstance which may to some of our readers appear, perhaps, paradoxical, that the division of labour can be applied with equal success to mental operations, and that it ensures, by its adoption, the same economy of time. Perhaps a short account of its practical application, in the most extensive series of calculations ever executed, will offer an interesting illustration of this fact, whilst it at the same time affords an occasion for showing that the arrangements which ought to regulate the interior economy of a Manufactory, are founded on principles of deeper root than had been anticipated, and are capable of being usefully employed in paving the road to some of the sublimest speculations of the Human Mind.

In the midst of that excitement which accompanied the Revolution of France and the succeeding wars, the ambition of the Nation, unexhausted by a too fatal passion for military renown, was at the same time directed to the nobler and more permanent triumphs which mark the era of a People's greatness; which receive the applause of a grateful posterity long after their conquests have been wrested from them; and which perpetuate it to times when their existence as a Nation is told only by the page of History.

Amongst their enterprises of Science, the French Government was desirous of producing a series of Mathematical Tables of general use, which should facilitate the extension of the decimal system they had so recently adopted. They directed, therefore, their Mathematicians to construct "*le monument de Calcul, le plus vaste et le plus imposant qui eût jamais été exécuté ou même conçu.*"

Their most distinguished Philosophers, responding fully to their Country's call, created new methods for the laborious task, and a Work, completely answering the large demands of the Government, was produced in a remarkably short period of time.

M. Prony, to whom the superintendence of the whole was confided, in speaking of its commencement, observes: "*Je m'y livrai avec toute l'ardeur dont j'étois capable, et je m'oc-*

Manu- *“cupai d'abord du plan général de l'exécution. Toutes les conditions que j'avois à remplir* Sect. I.
 factures. *“nécessitoient l'emploi d'un grand nombre des calculateurs ; et il me vint bientôt à la pensée*
“d'appliquer à la confection de ces Tables la division du travail, dont les Arts de Commerce
“tirent un parti si avantageux pour réunir à la perfection de main-d'œuvre l'économie de la
“dépense et du temps.”

The ancient methods of computing Tables were quite inapplicable to such a proceeding. Great
 M. Prony therefore wished to avail himself of all the talent of his Country, and formed the French
 First Section of those who were to take part in this enterprise out of five or six of their Tables.
 most eminent Mathematicians.

First Section.—The duty of the First Section was to investigate amongst the various analytical expressions which could be found for the same function, that which was most readily adapted to simple numerical calculation by many individuals employed at the same time. This Section had little or nothing to do with the actual numerical work. When its labours were concluded, the formulæ, on the use of which it had decided, were delivered to the

Second Section.—This Section consisted of seven or eight persons having some considerable acquaintance with Mathematics, and their duty was to convert into numbers the formulæ put into their hands by the First Section, an operation of some labour ; and then to deliver out these formulæ to the members of the Third Section, and receive from them the finished calculations. The members of this Second Section had certain means of verifying these calculations without the necessity of repeating, or even of examining the whole of the work done by the Third Section.

Third Section.—The members of this Section, whose number varied from sixty to eighty, received certain numbers from the Second Section, and using nothing more than simple addition and subtraction, they returned to that Section the finished Tables. It is remarkable that nine-tenths of this Class had no further knowledge of Arithmetic than its first two rules which they were thus called upon to exercise, and that these persons were usually found more correct in their calculations, than those who possessed a more extensive knowledge of the subject.

When it is stated that the Tables thus computed occupy seventeen large folio volumes, some idea may perhaps be formed of the labour.

From that part executed by the Third Class, requiring the least knowledge and by far the greatest labour, and which may almost be termed mechanical, the First Class were entirely exempt. Such labour can always be purchased at an easy rate. The duties of the Second Class, although requiring it to execute considerable Arithmetical operations, were yet in some measure relieved by the higher interest necessarily felt in those more difficult operations.

The exertions of the First Class are not likely to require, upon another occasion, so much skill and labour as they did upon the first attempt at introducing such a method ; and when the completion of a Calculating Engine shall have produced a perfect substitute for the whole of the Third Section of computers, the attention of analysts will naturally be directed to render its mode of application most simple, by a new discussion of the methods of converting analytical formulæ into number.

Manu-
factures.

The proceeding of M. Prony in this celebrated system of calculation, much resembles that of a skilful person about to construct a cotton or silk mill, or any other similar establishment. Having from his own genius, or through the aid of his friends, found that some improved Machinery may be successfully applied to his pursuit, he makes drawings of his plans of the Machinery, and may himself be considered as constituting the First Section. He next requires the assistance of operative engineers capable of executing the Machinery he has designed, some of whom should understand the nature of the process to be adopted; and these constitute his Second Section. When a sufficient number of Machines have been made, a multitude of other operatives, possessed of a lower degree of skill, must be employed in using them, and these form the Third Section; and their work, and the just performance of the Machines, must be still superintended by the Second class.

Sect. I.

Arithmeti-
cal opera-
tions by
Machinery.

As the performance of Arithmetical calculations by Machinery may appear to our non-mathematical readers to be rather too large a postulate, and as it is connected with the subject of the *division of labour*, we shall endeavour in the course of a few lines to give them some slight perception of the manner in which it can be performed, and thus to remove a small portion of the veil which covers that apparent mystery.

Mathemati-
cal prin-
ciple.

That nearly all Tables of numbers which follow any law, however complicated, may be formed to a greater or less extent solely by the proper arrangements of the successive addition and subtraction of numbers befitting each Table, is a principle which we could only prove in the general to those well acquainted with Mathematics, but the mind will readily admit that it is not impossible by attending to the following example.

Let us consider the subjoined Table.

Terms of the Table.	Table.	1st Difference.	2d Difference.
1	1	3	2
2	4	5	2
3	9	7	2
4	16	9	2
5	25	11	2
6	36	13	2
7	49		

This is the beginning of a Table in very extensive use, which has been printed and re-printed very frequently in many Countries, and is called a Table of square numbers. Any number in the Table is found by multiplying the number which expresses the distance of that term from the commencement of the Table by itself; thus, 25 is the fifth term from the beginning of the Table, and 5 multiplied by itself, or by 5, is equal to 25. Let us now subtract each term of this Table from the next succeeding, and place the results in another column, which may be called 1st Difference column. If we again subtract each term of this first difference from the succeeding term, we find the result is always the number two. That such must always be the case, will appear to any person who takes the trouble to carry on the Table a few terms further. Now when once this is admitted as a known fact, it is quite clear that, provided the first term (1) of the Table, the first term (3) of the first difference, and the first term (2) of the second

Manu-
factures.

Sect. I.

or constant difference, are originally given, we can continue by simple addition the Table of square numbers to any extent. For the series of odd numbers may be formed by repeatedly adding the constant difference 2 to (3) the first of them, and we then necessarily have the series 3, 5, 7, &c.; and again by successively adding each of these to the first number (1) of the Table we produce the square numbers.

Having thus, we hope, thrown a little light upon the theoretical part, we will endeavour to show that the mechanical execution of such an engine is not so far removed from ordinary Machinery as might be conceived. Let the reader imagine three clocks placed on a table side by side, and having a thousand instead of twelve hours marked on the face of each, and every time a string is pulled, let them repeat the hours to which their hands point. Let him further suppose that two of the clocks, for the sake of distinction called A and B, have some mechanism by which the clock A advances the hour hand of the clock B one hour for each stroke it makes on its own bell; and let the clock B by a similar contrivance advance the hour hand of the clock C one hour for each stroke it makes upon its own bell. With such an arrangement, and having set the hour hand of the clock A to 2 o'clock, that of B to 3 o'clock, and that of C to 1 o'clock, let the reader imagine the strings of the repeating parts of the clocks pulled continually in the following order of succession. Pull the string of clock C; pull the string of clock B; pull the string of clock A.

Practical
illustration.

	Clock C Marks one.	1st Difference. Clock B Marks three.	2d Difference. Clock A Marks two.
Pull the string of C.	Strikes one.		
Pull the string of B.	{ The hour hand is advanced three, and the clock now marks four. }	Strikes three.	
Pull the string of A.	.....	{ The hour hand is advanced two, and the clock now marks five. }	Strikes two.
Pull the string of C.	Strikes four.		
Pull the string of B.	{ The hour hand is advanced five, and the clock now marks nine. }	Strikes five.	
Pull the string of A.	.....	{ The hour hand is advanced two, and the clock now marks seven. }	Strikes two.
Pull the string of C.	Strikes nine.		
Pull the string of B.	{ The hour hand is advanced seven, and the clock now marks sixteen. }	Strikes seven.	
Pull the string of A.	.....	{ The hour hand is advanced two, and the clock now marks nine. }	Strikes two.
Pull the string of C.	Strikes sixteen.		
Pull the string of B.	{ The hour hand is advanced nine, & the clock now marks twenty-five. }	Strikes nine.	
Pull the string of A.	.....	{ The hour hand is advanced two, and the clock now marks eleven. }	Strikes two.
Pull the string of C.	Strikes twenty-five.		
Pull the string of B.	{ The hour hand is advanced eleven, & the clock now marks thirty-six. }	Strikes eleven.	
Pull the string of A.	.....	{ The hour hand is advanced two, and the clock now marks thirteen. }	Strikes two.
Pull the string of C.	Strikes thirty-six.		
Pull the string of B.	{ Advances the hour hand thirteen, & the clock now marks forty-nine. }	Strikes thirteen.	
Pull the string of A.	.....		
&c.	&c.	&c.	&c.

Manu-
factures.

Sect. I.

If now only those hours struck or pointed at by the clock C be attended to and written down, it will be found that it produces the series of the squares of the natural numbers. Such a series could of course only be produced completely by this mechanism so far as the three first figures, but this is sufficient to give some idea of the construction, and was the point to which the first model of the Calculating Engine extended.

We have seen then that the effect of the *division of labour*, both in mechanical and in mental processes, is that it enables us to purchase for each process precisely that quantity of skill and knowledge which is required for it; we avoid employing any part of the time of a man who can get eight or ten shillings a day by his skill in tempering needles in turning a wheel which can be done for sixpence a day, and we equally avoid the loss of employing the invaluable time of an accomplished Mathematician in the lowest processes of Arithmetic.

The extent to which the *division of labour* can be carried seems not to be unlimited. We have already alluded in the first chapter to the case of making the tags of laces, in which it appeared that a saving of time occurred from uniting two processes in one operation. The *division of labour* cannot be successfully practised unless there exists a great demand for its produce, and it requires larger capital to be employed in those Arts in which it is used.

ON THE SIZE OF FACTORIES.

On examining the analysis* of the Art of pin-making, we find that ten individuals are employed in it, and supposing this arrangement to be such that the whole of the time of each person employed is fully occupied, it is at once apparent that to conduct an establishment for pin-making most profitably, the number of persons employed must be a multiple of ten. For if a person with small means has only sufficient capital to enable him to employ half that number of persons, they cannot each of them constantly adhere to the execution of one process, and if a Manufacturer employs any number not a multiple of ten, a similar result must ensue with respect to some portion of them.

Principle
relating to
the number
of persons
in a factory.

The same reasoning extends to all Manufactories which are conducted upon the principle of the *division of labour*, and we arrive at this conclusion, *when (from the peculiar nature of the produce of each Manufactory) the number of processes into which it is most advantageous to divide it is ascertained, as well as the number of individuals to be employed, then all other Manufactories which do not employ a direct multiple of this number, will produce the article at a greater cost.*

Large fac-
tories econo-
mize trans-
port of ma-
terial.

Hence arises one of the causes of the size of Manufacturing establishments which have increased with the progress of civilization.

But another circumstance which contributes to the same end arises also from the same cause. The material out of which the Manufactured article is produced, must in the

* We must again recall to the reader's memory that the analysis referred to is an approximative one, and that there are few factories in which every operative is at all times fully employed, although this is the object which they all strive to attain. We have given an individual instance as most likely to excite the attention, whilst we particularly wish to direct the reader to the general nature of the reasoning.

Manu-
factures.

Sect. I.

several stages of its progress be conveyed from one operator to the next in succession ; this can be done at least expense when they are all working in the same establishment. If the material is heavy, this reason acts with additional force ; but in cases where it is light, the danger arising from frequently removing it may render it desirable to have all the processes carried on in the same building. In the cutting and polishing of glass this is the case, whilst in the Art of needle-making, several of the processes are carried on in the cottages of the workmen. It is, however, clear that the latter plan, which is attended with some advantages to the family of the workmen, can be adopted only where there exists a sure and quick method of knowing that the work has been well done, and that the whole of the materials given out have been really employed.

The inducement to contrive Machines for any process of Manufacture increases with the demand for the article, and the introduction of Machinery on the other hand tends to increase the quantity produced.

An illustration of these principles may be found in the commencement of the Manufacture of patent net. The first Machines for weaving it were very expensive, costing from £1000 to £1200 or £1300. The possessor of one of these Machines although it greatly increased the quantity of lace he could produce, was yet unable, when working eight hours a day, to compete with the old methods. This arose from the large capital invested in the Machinery ; but he quickly perceived that with the same expense of fixed, and a small addition to his circulating capital, he could work the Machine during the whole twenty-four hours.

The profits thus realized soon induced other persons to direct their attention to the improvement of those Machines, and the price was considerably reduced at the same time that the rapidity of production of the patent net was increased. If Machines are kept working through the twenty-four hours, it is necessary that some person shall attend to admit the workmen at the time they relieve each other, and whether the porter or other servant so employed admit one person or twenty, his rest will be equally disturbed. It is also necessary occasionally to adjust or repair the Machine ; and this will be done much better by a workman accustomed to Machine-making, than by the operative who uses it. Now since the good performance and the duration of Machines depend to a very great extent upon correcting, as soon as it appears, any shake or imperfection in their parts, it will soon become apparent that a workman resident on the spot will economize the wear and tear of the Machinery. But in the case of a single lace-frame, or a single loom, this would be too expensive a plan. Here then arises another circumstance which tends to enlarge the extent of a factory. It ought to consist of such a number of Machines as shall occupy the whole time of one workman in keeping them in order, and in making any casual repairs ; if it is extended beyond this, the same principle of economy points out the necessity of doubling or tripling the number of Machines in order to employ the whole time of two or three skilful workmen.

Enable Ma-
chines to be
worked all
night.

Where one part of each operative's labour consists in the exertion of mere Physical force, as in Weaving and many similar Arts, it will soon occur to the Manufacturer, that if the loom or lace-frame were driven by a steam-engine, the operative might attend to two

Introduces
steam
power.

Manu-
factures.

Increased
speed of
Machines.

Account-
ant's de-
partment.

Mode of
paying for
work in
mines in
Cornwall.

or more looms at once ; and since we already suppose that he has employed one or more operative engineers, he may so arrange the number of his looms that the charge of keeping them and the steam-engine in order, shall just fully occupy their time. One of the first effects will be that the steam-engine can drive the looms twice as fast as human force, and as each operative, when relieved from bodily labour, can attend to two looms, it will be found that one operative can now make as much cloth as four could do previously. This increase was greater than that which really took place at first, for the limit of the velocity of the parts of the loom depended upon the strength of the thread, and the quickness with which it commenced its motion : but an improvement was soon made by which the motion commenced slowly, and gradually acquired greater velocity than it was safe to give it at once. This improvement increased the speed from 100 to about 120 strokes per minute. Pursuing the same principles, the Manufactory becomes gradually so enlarged, that the expense of lighting during the night amounts to a considerable sum, and as there are already attached to the establishment persons who are up all night, and can therefore constantly attend to it, and also operative engineers to make and keep in repair any Machinery, the addition of an apparatus for making gas to light the factory introduces a new extension, at the same time that it contributes, by diminishing the expense of lighting, and the risk of accidents from fire, to render the production of the Manufactured article at a diminished cost.

Long before a factory has reached this extent, it will have been found necessary to establish an accountant's department, with clerks to pay the workmen, and to see that they arrive at their stated times ; and this department must be in communication with the agents who purchase the raw produce, and with those who sell the Manufactured article.

It would be of great importance, if in every large establishment the modes of paying the different persons employed could be so arranged, that each should derive advantage from the success of the whole, and that the profits of the individuals should advance as the factory itself produced profit, without the necessity of making any change in the wages agreed upon. This is by no means an easy arrangement to effect, and particularly amongst that class whose daily labour procures them their daily meal. The system which has long been pursued in working the Cornish mines, although not exactly fulfilling these conditions, yet possesses advantages which make it worthy of attention, as having considerably approached towards them, and as tending to render fully effective the faculties of all engaged in it.

Almost the whole of the work both above and below ground is contracted for. The manner of making the contract is nearly as follows : at the end of every two months the work which it is proposed to carry on during the next period is marked out. It consists of three kinds of work. 1. *Tutwork*, which consists in sinking shafts, driving levels, and making excavations ; this is paid for by the fathom in depth, or in length, or by the cubic fathom. 2. *Tribute*, which is payment for raising and dressing the ore, by means of a certain part of its value when merchantable. It is this species of payment which produces such admirable effects. The miners, who are to be paid in proportion to the richness of the vein, and the quantity of metal actually extracted from it, naturally become

Manu-
factures.

Sect. I.

quick-sighted in the discovery of ore, and in estimating its value; and it is their interest to avail themselves of every improvement that can bring it more cheaply to market.

3. *Dressing*. The tributors, who dig and dress the ore, can seldom afford to dress the coarser parts of that which they raise at their contract price; they therefore leave it, and it is again let out to persons, who agree to dress it at an advanced price.

The lots of ore to be dressed, and the works to be carried on, having been marked out for some days, and having been examined by the men, a kind of auction is held by the captains of the mine, in which each lot is put up, and bid for by different gangs of men. The work is then offered at a certain price to the lowest bidder, who rarely declines it at the rate proposed.

The tribute is a certain sum out of every twenty shillings' worth of ore raised, and may vary from threepence in the pound to fourteen or fifteen shillings. The rate of earnings in tribute is very uncertain; if a vein which was poor when taken becomes rich, the men earn money rapidly; and instances have occurred in which each miner of a gang has earned a hundred pounds in the two months. These extraordinary cases are perhaps of more advantage to the owners of the mine than even to the men, for they are always accompanied by some improved vein, and they greatly stimulate the skill and industry of the men.*

OF THE EFFECTS OF GREAT CAPITALS EMPLOYED IN MANUFACTURES

We have seen that the circumstance of the *division of labour* tends to produce cheaper articles; thus it increases the demand, and gradually, by the effect of competition, or the hope of increased gain, causes large capitals to be embarked in extensive factories. Let us now examine the influence of such accumulation of capital directed to one object. In the first place it enables the most important principle on which the division of labour rests to be carried almost to its extreme limits; not merely the precise amount of skill is purchased which is necessary for the execution of each process, but throughout every channel of its passage, from that in which the raw material is procured, to that by which the finished produce is conveyed into the hands of the consumer, the same system of economy of skill prevails. The result of this is necessarily a great reduction in the expense of the article which is brought to market. The quantity of work produced by a given number of people is, from such an extended arrangement, greatly augmented.

In many of the large establishments of our Manufacturing districts, substances are employed which are the produce of remote Countries, and which are in several instances almost peculiar to a few situations. The discovery of any new locality where such articles exist in abundance, is a matter of great importance to any establishment consuming them largely, and it has been found in some instances that the expense of sending persons to great distances purposely to ascertain such facts, and to collect such produce, has been amply repaid. Thus it has happened that the snowy mountains of

Send to dis-
tance for
materials.

* For a detailed account of the method of working the Cornish mines, see a paper by Mr. John Taylor, *Transactions of the Geological Society*, vol. ii. p. 309.

Manu-
factures.

Sweden and Norway, as well as the warmer hills of Corsica, have been almost stripped of one of their vegetable productions by agents sent expressly from one of our largest establishments for the dyeing of calicoes. Sect. I.

Every part
of raw ma-
terial em-
ployed.

Amongst the causes which tend to the cheap production of any article, and which require additional capital, may be mentioned the care which is taken to allow no part of the raw produce out of which it is formed to be absolutely wasted. An attention to this circumstance sometimes causes the union of two Trades in one factory, which might otherwise naturally have been separated. An enumeration of the Arts to which the horns of cattle are applicable, furnishes a striking example of this kind of economy. The tanner who has purchased the hides separates the horns, and sells them to the makers of combs and lanterns. The horn consists of two parts, an outward horny case, and an inward conical-shaped substance, somewhat intermediate between indurated hair and bone.

The first process consists in separating by means of a blow against a block of wood these two parts.

The horny exterior is cut into three portions by means of a frame saw.

1. The lowest of these next the root of the horn, after undergoing several processes by which it is rendered flat, is made into combs.

Instance,
Horns of
cattle.

2. The middle of the horn, after being flattened by heat, and its transparency improved by oil, is split into thin layers, and forms a substitute for glass in lanterns of the commonest kind.

3. The tip of the horn is used by the makers of knife-handles, and of the tops of whips, and for other similar purposes.

4. The interior or core of the horn is boiled down in water. A large quantity of fat rises to the surface, this is put aside, and sold to the makers of yellow soap.

5. The liquid itself is used as a kind of glue, and is purchased by the cloth-dressers.

6. The bony substance which remains behind is then sent to the mill, and being ground down is sold to the farmers for manure.

Besides these various purposes to which the different parts of the horn are applied, the clippings which arise in comb-making are sold to the farmer for manure at about one shilling a bushel. In the first year they have comparatively little effect, but during the next four or five their efficiency is considerable.

The shavings arising from the lantern-maker are of a much thinner texture, a few of them are cut into various figures and painted, and used as toys; for being hygrometric they curl up when placed in the palm of a warm hand. But the greater part of these shavings are sold to the farmers for manure, which from their extremely thin and divided form produces its full effect upon the first crop.

Middle-
men.

Another event which has arisen, in one Trade at least, from the employment of large capital, is that a class of middle-men, who were formerly interposed between the maker and the merchant, now no longer exists. In the printed-cotton trade this has arisen from two causes, the diminished cost of production in large establishments, although, perhaps, the most important, has not been the sole reason. In order to explain the other cause

Manu-
factures.

Set. I.

which has contributed to this change, we must advert to a principle of Political Economy which perhaps still requires a more enlarged discussion.

The *cost* of an article, at any given period, is stated to depend upon *the proportion between the supply and the demand*, which is true so far as the principle extends: but the *average cost* of any article through a long period, is stated to rest ultimately on the power of producing it and of selling it, with the ordinary profits of capital.

Now the cost of any article to the purchaser includes another element, which, although in most cases of little importance, is of great consequence in others.

The cost to the purchaser is the price he pays for any article, added to the cost of verifying the fact of its having that degree of goodness for which he contracted. In some cases the goodness of the article is evident on mere inspection, and in those cases there is not much difference of price at different shops. The goodness of loaf-sugar, for instance, can be discerned almost at a glance; and the consequence is, that the price of it is so uniform, and the profit upon it so small, that no Grocer is at all anxious to sell it; whilst, on the other hand, tea, of which it is exceedingly difficult to judge, and which can be adulterated by mixture so as to deceive the skill even of a practised eye, has a great variety of different prices, and is that article which every Grocer is most anxious to sell to his customers.

Cost to pur-
chaser is
price added
to verifica-
tion.

The expense of verification is, in some instances, so considerable, as to justify the deviation from well-established principles. Thus it has been found so difficult to detect the adulteration of flour and to measure its good qualities, that, contrary to the maxim, *that Government can generally purchase any article at a cheaper rate than that at which they can Manufacture it*, it has been found more economical to build extensive flour mills, (such are those at Deptford,) and to grind their own corn, than to verify each sack purchased, and to employ persons in continually devising methods of detecting the new modes of adulteration which might be resorted to. This principle has had its influence on the cotton trade. Formerly, when pieces of calico were woven in the cottages of the operatives, there existed a class of men who travelled about and purchased them, and collected them in large quantities, for the purpose of selling them to the exporting merchant. But the middle-man was obliged to examine each piece in order to know that it was perfect, and of full measure. Now, although the greater part of the operatives might be depended upon, yet the fraud of the few would make this examination necessary. For the value of character, although great in any circumstances of life, can never be so fully experienced by persons possessed of small capital as by those employing much larger sums. Any single cottager might hope if he were detected by one purchaser, that the fact would not become known to all the rest; whilst the larger the sums of money for which any merchant deals, the more is his character for punctuality studied and known by others. Thus it happens that high character supplies the place of an additional portion of capital; and the merchant, in dealing with the great Manufacturer, is saved from the expense of verification by his confidence that the loss, or even the impeachment of the merchant's character, would be attended with greater pecuniary detriment to him than any profit upon a single transaction could compensate.

Sometimes
cheaper to
make than
to verify.

Manu-
factures.
Character
instead of
verification.

The powerful influence of established character in producing confidence operated in a very marked manner at the time of the exclusion of British Manufactures from the Continent during the last war. One of our largest establishments had been in the habit of doing extensive business with a house in the centre of Germany, but on the closing of the Continental ports against our Manufactures, heavy penalties were inflicted on all those who contravened the Berlin and Milan Decrees. The English Manufacturer continued to receive orders, with directions how to consign them, and appointments for the time and mode of payment, in letters, the hand-writing of which was known to him, but which were never signed, except by the Christian name of one of the firm, and even in some instances they were without any signature at all. These orders were executed, and in no instance was there the least irregularity in the payments.

Price also
depends on
the number
of persons
holding the
supply.

Before we quit the subject of the *price* of a commodity, we must advert to two other circumstances which influence its amount. If the supply, or present stock in hand, is entirely in the possession of one person, he will naturally endeavour to put such a price upon it as shall produce by its sale the greatest quantity of money; but he will be guided in this estimate of the price at which he will sell it both by the knowledge that increased price will cause a diminished consumption, and by the desire to realize his profit before a new supply shall reach the market. If however the same stock is in the hands of several dealers there will be competition between them, arising partly from their different views of the duration of the present state of supply; and partly by their own peculiar circumstances with respect to the employment of their capital.

And on the
durability
of the ar-
ticle.

Again, if the commodity is itself of a perishable nature, such for example as a cargo of ice imported into the port of London from Norway a few Summers since, then time will supply the place of competition, and whether it is in the possession of one or of many persons it will scarcely reach a monopoly price.

POSITION OF FACTORIES.

It is found in every Country that the situation of large Manufacturing establishments is confined to particular districts. In the earlier history of a Manufacturing community, before cheap modes of transport have been extensively introduced, it will almost always be found that the article will be manufactured near those spots in which Nature has produced the raw material.

Factories
placed near
water
power,

In the heavier articles, and in those the value of which depends more upon the material than upon the labour expended on it, this will most frequently be the case. Most of the metallic ores being exceedingly heavy, and being mixed up with large quantities of weighty and useless materials, must be smelted at no great distance from the spot which produces them; fuel and power are the requisites for reducing them, and any considerable fall of water in the vicinity will naturally be resorted to for aid in all the coarser exertions of Physical force; for pounding the ore, blowing the furnaces, or for hammering and rolling out the iron. There are indeed peculiar circumstances which will modify this. Iron, coal, and limestone usually occur in the same district; but the

or coals for
steam,

Manu-
factures. union of the fuel in the same locality with the ore does not occur with respect to other Sect. I.
metals. In Cornwall there exist mines of copper and of tin, but none of coal. The copper ore which requires the largest quantity of fuel for its reduction is conveyed by ships to the coal fields of Wales, and is smelted at Swansea; whilst the vessels which convey it take back cargoes of coals to supply the steam-engines for draining the mines, and to smelt the tin, which requires a much less quantity of fuel for that purpose.

Rivers passing through districts rich in coal and metals, will form the first high roads or rivers for
carriage. for the conveyance of weighty produce to stations in which other conveniences present themselves for the further application of human skill. Canals will succeed, or lend their aid to these; and the yet unexhausted applications of Steam and of Gas hold out a hope of attaining almost the same advantages for Countries to which Nature seemed for ever to have denied them. Manufactures, Commerce, and Civilization ever follow the line of new and cheap communications. Twenty years ago the Mississippi poured the vast volume Mississippi. of its waters in lavish profusion through thousands of miles of Countries, which scarcely supported a few wandering and uncivilized Tribes of Indians. The power of the stream seemed to set at defiance the efforts of man to ascend its course, and as if to render the task still more hopeless, immense trees torn from the surrounding forests were planted in its bottom, forming in some places a barrier, in others the nucleus of a bank, and accumulating in the same spot, which but for accident would have been free from either, the difficulties and dangers of sand-banks and of rocks. Four months of incessant toil could scarcely convey a small bark with its worn-out crew two thousand miles up this stream. The same voyage is now performed by large vessels impelled by steam, carrying hundreds of passengers enjoying all the comforts and luxuries of civilized life, in the short period of ten days. Instead of the hut of the Indian, and the far more unfrequent log-house of the thinly scattered settlers, villages, towns, and cities have arisen on its banks; and the same engine which stemmed the force of these powerful waters, will probably tear from their bottom the obstructions which have hitherto impeded and rendered dangerous their navigation.

Although the price of any article may be reduced in its ultimate analysis to the quantity of *labour* by which it was produced, yet it is usual in a certain stage of the Manufacture of most substances to call them by the term *raw material*. Thus iron when Of raw ma-
terial. reduced from the ore and rendered malleable, is in a state of preparation for a multitude of useful purposes, and is the *raw material* out of which most of our tools are made. In this stage but a moderate quantity of *labour* has been expended on the substance, and it becomes an interesting subject to trace the various proportions in which *raw material* and *labour* are united to constitute the value of many of the productions of the Arts.

Gold-leaf consists of a small portion of the metal beat out to so great a degree of thinness, as to allow a greenish-blue light to be transmitted through its pores. About 400 square inches of this are sold in the form of a small book, containing 25 leaves of gold, for 1s. 6d. In this case, the raw material, or gold, is worth rather less than two-thirds Proportions
between raw
material
and labour, of the manufactured article. In the case of silver-leaf the labour considerably exceeds

Manu-
factures.

the value of the material. A book of fifty leaves, covering above 1000 square inches, is sold for 1*s.* 3*d.*

Sect. I.

Gold chains
of Venice.

In the fine gold chains made at Venice, we may trace in the various prices and sizes the relative influence of the two causes. The sizes of these chains are known by numbers, the smallest being originally No. 1, and the numbers 2, 3, 4, &c. each increasing in size. The following Table shows the numbers and the prices of those now made.* The first column is the number by which the chain is known, the second expresses the weight in grains of one inch in length of each chain, the third column shows the number of links in one English inch, and the last expresses the price in francs of a Venetian braccio, or about two English feet of each chain.

VENETIAN GOLD CHAINS.

No.	Weight of one inch. Grains.	Number of links in one inch.	Price of a Venetian Braccio, equal to 2 feet $\frac{1}{2}$ inch English.
0	.44	98 to 100	60
1	.56	92	40
1 $\frac{1}{2}$	.77	88	26
2	.99	84	20
3	1.46	72	20
4	1.61	64	21
5	2.09	64	23
6	2.61	60	24
7	3.36	56	27
8	3.65	56	29
9	3.72	56	32
10	5.35	50	34
24	9.71	32	60

In watch
balance
spring.

Amongst these chains that numbered 0, and that numbered 24, are exactly of the same price, although the quantity of gold in the latter is twenty-two times as much as in the former. The difficulty of making the smallest chain is so great, that the women who make it cannot work above two hours at a time. As we advance from the smaller chain, the proportionate value of the work to the worth of the material becomes less and less, until at the numbers 2 and 3, these two elements of its cost balance each other, after which the difficulty of the work decreases, and the value of the material increases. The quantity of labour applied to these chains is, however, incomparably less than that which is applied to some of the Manufactures of iron. In the case of the smallest chain the value of the labour is not above thirty times that of the gold. The pendulum spring of a watch which governs the vibrations of the balance, costs at the retail price two-pence, and weighs fifteen hundredths of a grain, whilst the retail price of a pound of the

* This was in 1828; a still finer chain is now (1831) manufactured.

Manu- best iron, the raw material out of which above fifty-thousand such springs may be made, Sect. I.
 factures. is exactly the same sum of two-pence.

OF THE PROPER CIRCUMSTANCES FOR THE APPLICATION OF MACHINERY.

The first object of Machinery, and that which gives to it its most extensive utility, is the cheap production of the articles to which it is applied. Wherever it is required to produce a great multitude of articles, all of exactly the same kind, the proper time has arrived for the construction of tools or Machines by which they may be Manufactured. If only a few pairs of cotton stockings should be required in a Country, or in circumstances in which it is impossible to purchase them, it would be an absurd waste of time, and of capital, to construct a stocking-frame to weave them, when for a few pence four steel wires may be procured by which they may be knit. If, on the other hand, many thousand pairs were wanted, the time employed, and the expense incurred in constructing a stocking-frame, would be more than repaid by the saving of time in making that large number of stockings. The same principle is applicable to the copying of letters: if only three or four copies are required, the pen and the human hand furnish the cheapest resource, but if hundreds of thousands of copies are required, the Machinery of a Printing establishment is the most economical method of accomplishing the object.

Principles which render the application of Machinery suitable.

There are, however, many cases in which Machines or tools must be made, where economical production is not the most important object. Whenever it is required to produce a few articles, parts of Machinery for instance which must be executed with the most rigid accuracy, it becomes nearly impossible to fulfil this condition, even with the aid of the most skilful workmen. In such circumstances it is necessary to make tools for the purpose, although those tools should, as frequently happens, cost more in constructing than the things they are destined to make.

Another instance of the just application of Machinery even at an increased expense, arises where the shortness of time in which the article can be produced, has an important influence on its value. In the publication of a daily newspaper, it frequently happens that the debates in the Houses of Parliament are carried on to three and four o'clock of the morning, that is to within a very few hours of the time of the publication of the newspaper. The speeches must be taken down by Reporters, transcribed by them, conveyed to the establishment of the newspaper, perhaps at the distance of two miles, set up by the Compositor, the press corrected, and papers printed off before the Public can read them. Some of these periodicals have a circulation of from five to ten thousand daily. Supposing eight thousand to be wanted, and that they could be printed only at the rate of five hundred per hour, (on one side,) which was the greatest number two journeymen and a boy could take off by the old hand-presses, it would require sixteen hours for the complete edition, and the news conveyed to the purchasers of the latest portion of the edition would be out of date before they could receive it. To obviate this difficulty, the paper was obliged to be set up in duplicate, and sometimes, when late, in triplicate; but the improvements in the printing Machines have been so great, that four thousand copies are now printed in an hour.

Printing quickly.

Manu-
factures.
Conveyance
of letters.

Sect. I.

The conveyance of letters is another instance in which the importance of saving time would allow of great expense in any new Machinery for its accomplishment. There is a natural limit to the speed of horses which even the greatest improvements in the breed, aided by an increased perfection in our public roads, can never surpass; and from which perhaps we are at present not very remote. When we reflect upon the great expense of time and money which the last refinements of a Theory or an Art usually require, it is not unreasonable to suppose the period has arrived in which the substitution of Machinery for such purposes ought to be tried.

The post bag despatched every evening by the mail to one of our largest cities, Bristol usually weighs less than a hundred pounds. Now the first reflection which naturally presents itself is, that in order to transport these letters a hundred and twenty miles, a coach and apparatus weighing above thirty hundred weight is put in motion, and also conveyed over the same space.*

It is obvious that amongst the conditions of Machinery for accomplishing such an object, it would be desirable to reduce the weight of matter to be conveyed with the letters; it would also be desirable to reduce the velocity of the animal power employed, because the faster a horse is driven, the less weight he can draw. Amongst the variety of contrivances which might be imagined, we will mention one which, although by no means free from objections, fulfils some of the prescribed conditions, and is not a purely theoretical speculation, since we have seen on an extremely limited scale some few experiments upon it.

Let us imagine a series of high pillars erected at frequent intervals, perhaps every hundred feet, as nearly as possible in a straight line between the two post towns. An iron or steel wire of some thickness must be stretched over proper supports fixed on each of these pillars, and terminating at the end of every three or five miles, as may be found expedient, in a very strong support, by which it may be stretched. At these points a man ought to reside in a small station-house. A narrow cylindrical tin case to contain the letters might be suspended by two wheels rolling upon this wire; these might be so constructed as to enable them to pass unimpeded by the fixed supports of the wire. An endless wire of much smaller size must pass over two drums, one at each end. This wire should be supported on rollers, fixed to the supports of the great wire, and at a short distance below it. With this arrangement there would be the two branches of the smaller wire always accompanying the larger one, and the attendant at either station might, by turning the drum, cause these two branches of the small wire to move with great velocity in opposite directions. In order to convey the cylinder which contains the letters, it would only be necessary to attach it by a string or by a catch to either of the branches of the endless wire. Thus it would be conveyed speedily to the next station, where it would be removed by the attendant to the commencement of the next wire, and thus transmitted on.

* It is true that the transport of letters is not the only object which this apparatus answers, but the transport of passengers, which is a secondary object, does in fact put a limit to the velocity of that of letters, which is the primary one.

Manu-
factures.

Sect. I.

It is not our intention to enter into the details which this or some similar plan would require. It is sufficient to observe that it is attended with its difficulties, but that when they are overcome, it will present many advantages besides velocity. For if an attendant reside at each station, the additional expense of having two or three deliveries of letters every day, and even of sending expresses at any moment, will be comparatively trifling, and it is not impossible that the stretched wire may itself be available for a species of telegraphic communication yet more rapid.

We shall mention one other instance in which the object to be obtained is so important, that although it might be rarely wanted, yet Machinery for that purpose would justify considerable expense. A vessel to contain men, and to be navigated at some distance below the surface of the sea, would in many circumstances be almost invaluable. Such a vessel evidently could not be propelled by any engine requiring the aid of fire. If, however, by condensing air into a liquid, and carrying it in that state, a propelling power could be procured sufficient for moving the vessel through a considerable space, the expense would scarcely render its occasional employment impossible.

Submarine
navigation.

The power of inventing mechanical contrivances and of combining Machinery does not appear, if we may judge from the frequency of its occurrence, to be a rare gift; and amongst the vast multitude of inventions which have been produced almost daily for a series of years, a large part have failed from the imperfect nature of the first trials; whilst a still larger portion, which had escaped the mechanical difficulties, have failed, because the economy of their operations had not been attended to.

Invention
in Mecha-
nics not
difficult.

To produce movements even of a complicated kind is not difficult. There exist a great multitude of known contrivances for all the more usual wants, and if the exertion of moderate power is the end of the mechanism to be contrived, it is possible to construct the whole Machine upon paper, and to judge of the proper strength to be given to each part as well as to the framework which supports it, and of its ultimate effect, long before a single part of it has been executed. In fact, all the contrivance and all the improvements ought to be made in the Drawings. On the other hand, there are circumstances dependent upon Physical or Chemical properties for which no drawings will be of any use. These are the legitimate object of direct trials.

Proper
subjects for
drawings.

For example, if the ultimate result of an engine is to be that it shall impress letters upon a copper-plate by means of steel punches pressed into it. All the mechanism by which the punches and the copper are to be moved at stated intervals, and brought into contact, is entirely within the province of Drawing, and the Machinery may be arranged entirely upon paper. But a doubt may reasonably spring up whether the bur that will be raised round the letter which has been punched upon the copper may not interfere with the proper action of the punch for the letter which is to be punched next adjacent to it. It may also be feared that the act of punching the second letter, if it be sufficiently near to the first, might distort the form of that first figure. And if neither of these evils should arise, still the burs produced by the punching might be expected to interfere with the goodness of the impression produced by the copper-plate, and the plate itself, after having all but its edge covered with figures,

Proper sub-
jects for ex-
periments.Punching
letters in
copper.

Manu-
factures.

might, from the unequal condensation which it must suffer in this process, change its form, so as to render it impossible to take off impressions from it. It is impossible by any Drawings to solve these difficulties, experiment alone can determine their nature. Such experiments have been made, and it is found that if the sides of the steel punch are nearly at right angles to the face of the letter, a very inconsiderable bur is produced ;—that at the depth which is sufficient for copper-plate printing, no distortion of the adjacent letters takes place, although those letters are placed very close to each other ;—that the small bur which arises may easily be scraped off ;—and that the copper-plate is not distorted by the condensation of the metal, and is perfectly fit to print from, after it has undergone this process.

The next stage in the progress of an invention after the Drawings are finished, and the preliminary experiments have been made, if any such should be requisite, is the execution of the Machine. It can never be too strongly impressed upon the minds of those who are devising new Machines, that to make the most perfect Drawings of every part tends essentially both to the success of the trial, and to economy in arriving at the result. The actual execution from the working Drawings is comparatively an easy task, provided always that good tools are employed and that methods of working are adopted, in which the perfection of the part constructed depends less on the personal skill of the workmen, than upon the certainty of the methods they employ.

Causes of
failure in
new Ma-
chines.

The causes of failure in this stage most frequently arise from errors in the preceding one, and it is sufficient merely to indicate a few of their sources. They usually arise from having neglected to take into consideration that metals are elastic, and not perfectly rigid. A steel cylinder of small diameter must not be considered as an inflexible rod ; but in order to ensure its perfect action as an axis, it must be supported at proper intervals. Again, the strength and stiffness of the framing which supports the mechanism must be carefully attended to. It should always be recollected that the addition of superfluous matter to the immovable parts of a Machine, is not accompanied with the same evil that arises when the moving parts are too heavy ; for thus no additional momentum is generated.

The stiffness of the framing of a Machine draws after it another important advantage. If the bearings of the axes (those places at which they are supported) are originally placed in a straight line, they will continue so, whereas if the framework itself changes its form, although ever so slightly, considerable friction will immediately arise. This effect is so well understood in the districts in which our spinning factories are numerous, that in estimating the expense of working a new factory, it is allowed that five per cent. on the power of the steam-engine will be saved if the building is fire-proof. This saving arises entirely from the circumstance that the greater strength and rigidity of a fire-proof building allow the long shafts or axes which drive the Machinery to be unimpeded by the friction which would arise from the slightest deviation in any of the bearings.

It is quite a mistaken idea to suppose that any imperfect work is good enough for a trial. If the experiment is at all worth trying, it ought to be tried with all the advantages of which the state of Mechanical Art admits ; for an imperfect trial may cause an idea to

Manu-
factures.

be given up which better workmanship might have proved to be practicable. On the other hand, when once its success has been established with good workmanship, it will be easy to ascertain that degree of perfection which is necessary for its due action.

Sect. I.

It is partly owing to this circumstance, *the imperfection of the original trials*, and partly owing to the gradual improvement in the Art of making Machinery, that many inventions which have been tried and have been given up in one state of Art, have at another period been eminently successful. The idea of printing by means of movable types has probably suggested itself to the imagination of many men conversant with impressions taken either from blocks or seals. We find amongst the instruments discovered in the remains of Pompeii and Herculaneum, stamps consisting of letters formed out of one piece of metal. The idea of separating these and recombining a multitude of similar ones for the purpose of stamping a book, instead of the initials of its owner, could scarcely have failed to have occurred to many, and would certainly have been almost immediately rejected by those best versed in the Mechanical Arts of that time: for any workman of those days would have instantly perceived the impossibility of producing many thousand pieces of metal fitting so perfectly, and ranging so uniformly as the types which are used for printing. The principle of the press which bears the name of Bramah, was known about a century and a half before the Machine to which it gave rise existed; but the imperfect state of Mechanical Art in the time of its discoverer would have effectually deterred him, if it had occurred to his mind, from attempting to apply it as an instrument for exerting force.

Failure
may occur
from imper-
fect state of
Mechanical
Arts.

These considerations prove the propriety of repeating, at the termination of intervals during which the Art of making Machinery has undergone any great improvement, the trials of methods which have previously failed, although they were founded upon just principles.

When the Drawings have been properly made, and the Machine well executed, and when the work it produces possesses all the qualities which were anticipated, still the invention may fail; that is, it may fail of being brought into general practice. This will most frequently arise from the circumstance of its producing its work at a greater expense than that at which it can be made by the old methods.

Whenever the new, or improved Machine, is intended to become the basis of a Manufacture, it is essentially requisite that the whole expense of producing the article by its means should be fully considered before its construction is undertaken. It is almost always very difficult to make this estimate of the expense; but the more complicated the Machinery the less easy the task, and in cases of great complexity and extent of Machinery it is almost impossible. It has been estimated roughly, that the expense of making the first individual of any newly-invented Machine will cost about five times as much as the construction of the second, an estimate which is perhaps sufficiently near the truth. If the second Machine is to be made precisely like the first, the same Drawings and the same patterns will suffice; but if, as usually happens, some improvements have been suggested by the experience of the first, more or less of these must be altered. When, however, two or three Machines have been completed, and many more

Compara-
tive expense
of first trial.

Manu-
factures.

are wanted, they can usually be produced at much less than one-fifth of the expense of the original invention. The Arts of contriving, of Drawing, and of executing, do not usually reside in their greatest perfection in one individual, and in this, as in other Arts, *the division of labour* must be applied. The best advice which could be offered to a projector of any mechanical invention is to employ a respectable Draughtsman, who, if he has had a large experience in his profession, will be able to assist him in finding out whether his contrivance is new, and who will then make working Drawings of it. The first step, the ascertaining whether the contrivance has the merit of novelty, is most important, and it is not easy to get satisfactory evidence upon this point. It is one also on which projectors are often singularly negligent.

Sect. I.

Mechanical
projectors
frequently
ignorant.

There is, perhaps, no trade or profession existing, in which there is so much quackery, so much ignorance of the Scientific principles, and of the History of the Art with respect to its resources and extent, as is to be met with amongst mechanical projectors. The self-constituted Engineer, dazzled with the beauty of some, perhaps, really ingenious contrivance, assumes his new profession with as little conjecture that previous instruction, that thought and painful labour are necessary to its successful exercise, as does the Statesman or the Senator. Much of this false confidence arises from the improper estimate which is entertained of the difficulty of the invention of mechanical contrivances; and it is of great importance, both for the individuals and for the families of those who are thus led away from more suitable pursuits, the dupes of their own ingenuity and of the popular voice, to convince both parties that the invention of new contrivances by no means requires talents of the highest order, and that the power of making new mechanical combinations is a possession common to a multitude of minds. It is still more important that they should be convinced that the great merit and the great success of those who have succeeded in such affairs, has arisen from, and was almost entirely due to, the unremitted perseverance with which they concentrated upon the successful Machine the skill and knowledge which years of study had matured.

It is a maxim equally just in all Arts and in every Science, that *the man who aspires to fortune or to fame by new discoveries, must be content to examine with care the knowledge of his contemporaries, or to exhaust his efforts in inventing again what he will most probably find has been better executed before.*

DURATION OF MACHINERY.

The time during which a Machine will continue effectually to perform its work, will depend mainly upon the perfection with which it was originally constructed, upon the care taken to keep it in proper repair, particularly to correct every shake or looseness in the axes, and upon the small mass and slow velocity of its moving parts. Every thing approaching to a blow, all sudden change of direction is injurious. Engines for producing power, such as wind and water-mills and steam-engines, usually last a long time;*

* The return which ought to be produced by a fixed steam-engine employed as a moving power is frequently estimated at ten per cent. on its cost.

Manu-
factures.

Sect. I.

but Machinery for producing any commodity in great demand is of short-lived duration. It is seldom that Machinery of this class wears out; new improvements, by which the same operations can be executed either more quickly or better, generally supersede it long before that period arrives: indeed, to make such an improved Machine profitable, it is usually reckoned that in five years it ought to have paid itself, and in ten to be superseded by a better.

The effect of improvements in Machinery seems incidentally to increase production through a cause which may be thus explained. A Manufacturer making the usual profit upon his capital, which he has invested in looms or other Machines in perfect condition, the market price of making each of which is a hundred pounds, invents some improvement. But this is of such a nature that it cannot be added to his present engines. He finds upon calculation, that at the rate at which he can dispose of his Manufactured produce, each new engine would repay the cost of its making, together with the ordinary profit of capital, in three years: he also concludes from his experience of the trade, that the improvement he is about to make will not be generally adopted by other Manufacturers before that time. On these considerations, it is clearly his interest to sell his present engines, even at half-price, and construct new ones on the improved principle. But the purchaser who gives only fifty pounds for the old engines, has not so large a fixed capital invested in his factory as the person from whom he purchased them, and as he produces the same quantity of the Manufactured article, his profits will be larger. Hence the price of the commodity will fall, not only in consequence of the cheaper production by the new Machinery, but also by the more profitable working of the old, when sold at a reduced price. This change can be only transient, for a time will arrive when the old Machinery, although in good repair, must become worthless. The improvement which took place not long ago in frames for making patent net was so great, that a Machine, in good repair, which had cost £1200, sold a few years after for £60; during the great speculations in that trade, the improvements succeeded each other so rapidly, that Machines which had never been finished were abandoned in the hands of their makers, because new improvements had superseded their utility.

The duration of any commodity seems to influence its cost in a permanent manner. We have already stated that what may be called the momentary price of any commodity depends upon the proportion existing between the supply and demand, and also upon the cost of verification. The average price during a long period will depend upon the labour required in producing and bringing it to market, as well as upon the average supply and demand, but it will also be influenced by the *durability of the article Manufactured*. There are many articles in common use which are destroyed in using: thus a phosphorus match, a sheet of letter paper, and a segar, can never be used twice. There are others, few perhaps in number, which never wear out; the harder precious stones, when well cut and polished, are of this latter class. The fashion of the gold or silver mounting in which they are set may vary with the taste of the Age, and such ornaments are constantly exposed for sale as second-hand, but the gems themselves when removed from their supports are never so considered. A brilliant, which has successively

Price of a
commodity
perma-
nently in-
fluenced by
its durabi-
lity.

graced the necks of a hundred beauties, or glittered for a century upon Patrician brows, will be weighed by the diamond merchant in the same scale with another fresh from its native repository, which has just escaped from the wheel of the lapidary, and will be purchased or sold by him at the same price per carat. The great mass of commodities is intermediate in its character between these two extremes, and the periods of respective duration are very various. It is evident that those things which are consumed in the act of using them, can never have an average price which is less than that of the labour of bringing them to market. They may for a short time be sold for less, but their production must soon, under such circumstances, cease altogether. On the other hand, if an article never wears out, the consequence will be that its price may continue *permanently* below the cost of the labour expended in producing it, and the only consequence will be that no further production will take place. Its price will continue to be regulated by the relation of the supply to the demand; and should that at any after time rise, for a considerable period, above the cost of production, it will again be Manufactured. Articles become old from actual decay or wearing out of their parts; from improved modes of constructing them; or from changes in their form and fashion required by the varying taste of the Age. Under the latter two circumstances, their utility is but little diminished, and being less sought after by the classes who have hitherto employed them, they are sold at a reduced price to a class of Society rather below that of their former possessors; thus a taste for luxuries is propagated downwards in Society, and after a short period, the numbers who have thus acquired new wants are sufficient to excite the ingenuity of the Manufacturer to reduce the cost of making them, who thus benefits himself by the extended scale. Many articles of furniture, such as well-made tables and chairs, are thus found in the rooms of those who would have been quite unable to have purchased them when new; and we find constantly, even in the houses of the more opulent, large looking-glasses which have passed successively through many possessors, changing only the fashion of their frames; and in some instances this alteration is omitted, and an additional coat of gilding saves them from the character of being second-hand.

Manu-
factures.
Diamonds.
Looking-
glasses.

There is a peculiarity in looking-glasses with reference to this principle. They are most frequently injured by violence, and the peculiarity is, that unlike most other articles when broken, they are still of some value. If a large mirror is accidentally cracked, it is immediately cut into two or more smaller ones, each of which may be perfect. If the degree of violence is so great as to break it into many pieces, these smaller pieces will be cut into squares for dressing-glasses, and if the silvering is injured, it can either be resilvered or used as plate glass for windows. The addition from our Manufactories to the stock of plate-glass in the Country is annually about two hundred and fifty thousand square feet. It would be very difficult to estimate the quantity annually destroyed or exported, but it is probably small, and the effect of these continual additions is seen in the diminished price and increased consumption of the article. Almost all the better order of shop fronts are now glazed with it. If it were quite indestructible the price would gradually diminish, and unless an increased demand arose from new

Manu- uses or a greater number of customers, a single Manufactory, unchecked by competition, *Sect. I.* would ultimately be obliged to shut up, driven out of the market by the permanency of its own productions.

The relative value of the same Manufacture in different Countries being always an interesting inquiry, we have given the following Table.

Comparative Price of Plate Glass at the Manufactories of London, Paris, and Berlin.

Height.	Breadth.	London. 1827.			Paris. 1825.			Berlin. 1828.		
Inches.	Inches.	£.	s.	d.	£.	s.	d.	£.	s.	d.
16	16	0	17	6	0	9	9	0	5	5
30	20	2	6	10	2	2	0	1	14	0
50	30	6	12	10	11	0	0	10	2	0
60	40	13	9	6	26	11	0	25	5	0
76	40	19	3	0	42	11	0	40	17	0
90	50	34	12	9	82	18	0			
100	75	74	5	10	269	8	0			
120	75	97	15	9	524	18	0			

The price of silvering these glasses is 20 per cent. on the cost price for English plate, and 10 per cent. on the cost price for Paris and Berlin plates.

OF COMBINATIONS AMONGST MASTERS OR WORKMEN.

There exist amongst the operatives of almost all classes certain rules or laws which govern their actions towards each other and towards their employers. But besides these general principles, there are usually others peculiar to each factory, which have arisen in many instances for the mutual convenience of the several parties engaged in them. Such rules are little known except to those actually pursuing the several trades, and as it is of importance that their advantages and disadvantages should be canvassed, we shall offer a few remarks upon some of them. The principles by which such laws should be tried are,

1st. *That they conduce to the general benefit of the whole of the persons employed.*

2dly. *That they prevent fraud.*

3dly. *That they interfere as little as possible with the free agency of each individual.*

It is usual in many workshops, that on the first entrance of a new journeyman, he shall pay a small fine to the rest of the men. It is clearly unjust to insist on this payment, and when it is spent in drinking, which is unfortunately too frequently the case, it is injurious. The reason assigned for the demand is, that the new comer will require some instruction in the habits of the shop, and in the places of the different tools, and will thus waste the time of some of his companions until he is instructed. If this fine

Rule of
particular
factories.

**Manu-
factures.** were added to a fund managed by the workmen of the establishment, and divided at given periods, or destined for their relief in sickness, it would be less objectionable, since its tendency would be to check the too frequent change of the men from one shop to another. But it ought, at all events, not to be compulsory, and the advantages to be derived from the fund to which he is invited to subscribe ought to be the workman's inducement.

In many workshops, the workmen, although employed in totally different parts of the objects Manufactured, are yet dependent in some measure on each other. Thus a single smith may be able to forge in one day enough work to keep four or five turners employed during the next. If from idleness or intemperance, the smith neglects his work, and does not furnish the usual supply, the turners (supposing them paid by piece-work) will have their time partly unoccupied and their gains consequently diminished. It is reasonable in such circumstances that a fine should be levied, in order to prevent their recurrence; but it is desirable that the master should have concurred with his workmen in establishing such a rule, and that it should be shown to each individual previous to his engagement; and it is very advisable that such fine should not be spent in drinking.

**Premium
for remark-
able skill.**

In some establishments it is customary for the master to give a small gratuity whenever any workman has exercised a remarkable degree of skill, or has economized the material employed. Thus in splitting horn into layers for lanterns, one horn usually furnishes from five to eight layers; but if a workman splits one horn into ten or more, he receives a pint of ale from the master. Such regulations, when judiciously made, are very desirable, as they tend to promote skill amongst the operatives, profit to the masters, and diminished cost to the consumers.

In some few factories, in which the men are paid by piece-work, it is usual, when any lot of work delivered in by a workman is rejected by the master on account of its being badly executed, to fine the delinquent. Such a practice tends to remedy one of the evils attendant upon that mode of payment, and greatly aids the master, since his own judgment is thus supported by competent and unprejudiced judges.

**Association
to fix the
relative
value of
work.**

There are Societies formed amongst larger bodies of workmen, and also by the masters engaged in the same branch of trade, which have other objects in view; and it is very desirable that these should be well understood by the individuals who compose them, and that the advantages arising from them, which are certainly great, should be separated as much as possible from the evils which have unfortunately been too frequently introduced by them. Associations of operatives and of masters may, with advantage, agree upon rules to be observed by both parties in the estimation of the proportionate value of various kinds of work executed in their trade, in order that time may be saved, and disputes between them may be prevented. They may also be most usefully employed in acquiring accurate information of the number of operatives working in the various departments of any Manufacture, their rate of wages, the number of Machines in use among them, and other statistical details. Information of this nature is extremely valuable both for the guidance of the parties who are themselves most interested, and also to enable them, on any application to Government for assistance or for Legislative

Manu-
factures. enactments, to supply those details, without which the propriety of any proposed measure cannot be fitly decided upon. Such details may be collected by men engaged in any trade, at a much smaller expense of time than by persons less acquainted with and less interested in it. Sect. I.

A species of combination occasionally takes place amongst Manufacturers against persons having Patents. These combinations are always injurious to the Public as well as unjust to the inventors. Some years since a gentleman invented a Machine, by which modellings and carvings were cut in mahogany and other fine woods. The Machine resembled, in some measure, the drilling apparatus employed in ornamental lathes; it produced beautiful work at a very moderate expense. But the cabinet-makers met together, and combined against it, and the Patent has consequently never been worked. A similar fate awaited a Machine for cutting veneers by means of a species of knife. In this instance the wood could be cut thinner than by the circular saw, and no waste of it was incurred; but the trade set themselves against it, and after a heavy expense it was given up. Combina-
tion of
masters
against
Patents.

Similar examples of combination seem not to be unfrequent, as appears by the Report of the Committee of the House of Commons on Patents for Inventions, June, 1829. See the evidence of Mr. Holdsworth.

The effects arising from combinations either amongst the master Manufacturers, or amongst the men, are almost always injurious to the Public, and are generally so to the parties themselves. There are, however, numerous instances in which, although the Public suffer by increased price at the moment, they are ultimately gainers from the permanent reduction which results; whilst, on the other hand, the improvements which are often made in Machinery in consequence of a strike amongst the workmen, most frequently do a permanent injury to that particular class which gave rise to them. As the injury to the operatives and to their families is almost always more considerable than that which overtakes their employers, it is of the greatest importance for the comfort and happiness of the former class, that sound views should be entertained by them upon this question. For this purpose a few illustrations of the principle we are maintaining will probably have greater weight than any reasoning of a more general nature, though drawn from admitted principles of Political Economy. Such instances will moreover present the additional advantage of appealing to facts known to many individuals of those classes for whose benefit these reflections are intended. Effect of
combina-
tions

About twenty years ago, the workmen employed in a particular branch of the gun-making trade, struck for an advance of wages. The process on which these men were employed was the making what are called, in the language of the trade, *skelps*.

The *skelp* is a piece or bar of iron, about eighteen inches long, and between two and three broad, thicker at one end than at the other. The barrel of a musket is formed by forging out such pieces to the proper length, and then turning round the edges until they meet, in which state they are welded together.

The persons employed in forging the skelps out of bar-iron struck for an advance of wages, and as their demands were high, they were not immediately complied with. In Instance in
gun-barrels.

Manu-
factures.

the mean time, the superintendent of the establishment directed his attention to the subject, and it occurred to him that if the circumference of the iron rollers between which the bar-iron was rolled were to be made equal in length to two skelps, or to two musket barrels, and if also the groove in which the bar-iron was compressed, instead of being equally deep, were cut gradually deeper from one point in the cylinders to a point exactly opposite, and if it were then gradually diminished in depth until it returned to the first point, then the bar-iron passing between such rollers, instead of being square, would have the form of a series of skelps, each pair of which would be united together at the thicker ends, and these couples would be united to each other by the thinner ends. On making the trial, it was found to succeed perfectly ; a great diminution of human labour took place in that process, and the operatives who had acquired peculiar skill in that particular branch ceased to derive any advantage from it.

Second in-
stance in
gun-
making.

It is somewhat singular that another and a still more remarkable instance of the effect of combination amongst workmen should have occurred but a few years since in the very same trade. The process of welding up the gun-barrels required much skill, and since the termination of the war, the demand for muskets having greatly diminished, the number of operatives in that line was small. This circumstance rendered combination more easy, and upon an occasion when a contract had been entered into for a considerable supply to be delivered at a fixed day, all the men struck for so great an advance of wages as would have caused the completion of the contract to be attended with a very heavy loss. In this difficulty, it occurred to the contractors to make a new trial of a plan for which they had formerly taken out a Patent, but which had never been brought into use. Their process consisted in turning up the skelp into the form of a cylinder, with the edges a little overlapping ; they were then placed in a furnace. When raised to a welding heat, they were taken out, and a triblet, or cylinder of iron, being placed in each, it was passed quickly through a pair of rollers. The effect of this was, that the skelp was drawn out and welded at one heat, and the remainder of the elongation necessary for bringing it to the length of the musket barrel, was performed in a similar manner, but at a lower heat. The operatives who had combined were, of course, no longer wanted, and as the process to which they had been habituated required peculiar skill and considerable experience, they had hitherto been in the habit of earning much higher wages than other workmen of their class. They were, therefore, instead of benefiting themselves by their combination, reduced permanently, in consequence of this improvement in the Art, to a considerably lower rate of wages. On the other hand, the new method of welding was far less injurious to the texture of the iron, in consequence of its being exposed only once, instead of three or four times, to the welding heat, so that the Public derived advantage from the superiority, as well as from the economy of the process. Another advantage has also arisen, for the new process is now applied to the manufacture of iron tubes, which can thus be made at a price which renders them much in demand. Other examples must have presented themselves to those who are familiar with the details of our Manufactories, but these are sufficient to illustrate one of the results of combinations. It would not, however, be fair to push the conclusion deduced

Manu-
factures.

from these examples to its extreme limit. Although it is very apparent that in the two cases which have been stated the effects of combination were permanently injurious to the operative by almost immediately placing him in a lower class (with respect to his daily earnings) than he occupied before; yet they do not prove that *all* such combinations have this effect. It is quite evident that they all have this *tendency*; it is also certain that considerable stimulus must be applied to induce a man to contrive a new process; and that in both these cases, unless the fear of pecuniary loss had acted powerfully, the improvement would not have been made. If, therefore, the workmen had in either case combined for only a small advance of wages, they would, in all probability, have been successful, and the Public would have been deprived for many years of the invention to which these combinations gave rise. The consequence of combination, then, has been to the workmen who combined, reduction of wages; to the Public, reduction of price; and to the Manufacturer, increased sale of his commodity resulting from that diminution of price. It is, however, important to consider the effects of combination in another and less obvious point of view.

The fear of combination amongst the operatives whom he employs will have a tendency to induce the Manufacturer to conceal from his workmen the extent of the orders he may at any time have in hand, and consequently at all times they will know less of the extent of the demand for their labour than they otherwise might. This is injurious to their interests; for instead of foreseeing, by the gradual falling off in the orders, the approach of a time when they must be unemployed, and preparing accordingly, they are liable to much more sudden changes than those to which they would otherwise be subject. As the Manufacturer, when he makes a contract, has no security that a combination may not arise amongst the operatives, which may render that contract a loss instead of a benefit; besides taking precautions to prevent them from becoming acquainted with it, he must also add to the price at which he could otherwise sell the article, some small increase to cover the risk of such an occurrence. If an establishment consist of several branches which can only be carried on jointly, as, for instance, of iron mines, blast furnaces, and a colliery, in which there are distinct classes of operatives, it becomes necessary to keep on hand a larger stock of materials than would be required, if it were certain that no combinations would arise amongst the operatives. Suppose, for instance, the colliers were to strike for an advance of wages, unless there was a stock of coal above ground, the furnaces also must be stopped, and the miners also would be thrown out of employ.

Now the cost of keeping a stock of iron ore or of coals above ground, is just the same as that of keeping unemployed in a drawer its value in money, (except, indeed, that the coal suffers a small deterioration by exposure to air.) The interest of this sum must therefore be considered as the price of an insurance against the risk of combination amongst the workmen; and it must, so far as it goes, increase the price of the Manufactured article, and consequently limit the demand which would otherwise exist for it. But every circumstance which tends to limit the demand, is injurious to the workmen, because the wider the demand the less it is exposed to fluctuation. The effect to

Sect. I.

Disadvan-
tages to
operatives.Capital
lying unem-
ployed in
consequence
of fear of
combina-
tion.

Manu-
factures.

which we have alluded is by no means a theoretical conclusion; the proprietors of one establishment in the trade we have mentioned, think it expedient always to keep above ground a supply of coal for six months, which is in that instance equal in value to about 10,000*l*.

ON THE EFFECT OF TAXES AND OF LEGAL RESTRICTIONS UPON MANUFACTURES.

Effects of
taxes

on paper,

on light,

on iron.

Effects of
fixed sizes.

Effects of
removal of a
monopoly.

Whenever Government puts a tax upon any article, the ingenuity of those who make and who use it will immediately become directed to the means of evading as large a part of that tax as they can, and this will often be accomplished in ways that are perfectly fair and legal. An excise duty exists at present of 3*d*.^{*} per pound upon all writing-paper. The effect of this impost is, that much of the paper which is employed is made extremely thin, in order that the weight of a given number of sheets may be as small as possible. Soon after the first imposition of the tax upon windows, which depended upon their number and not upon their size, new built houses began to have fewer windows and of a larger size than before. Staircases derived light from extremely long windows, illuminating three or four flights of stairs. When the tax was increased, and the size of windows charged as single was limited, then still greater care was taken to have as few external windows as possible, and internal lights became frequent. Thus in some instances a tolerable guess might be formed of the age of a house from the nature of its windows.

The effects of duties upon the import of foreign Manufactures are equally curious. A singular instance occurred in the article bar-iron, which is liable to a duty of 140 per cent. *ad valorem*, on introduction into the United States, whilst that upon hardware is 25 per cent. In consequence of this tax, large quantities of malleable iron rails for railroads were imported, and the difference of 125 per cent. in duty more than counterbalanced the expense of fashioning the iron into rails prior to its importation.

The circumstance of restricting the articles produced in a Manufactory to certain sizes, is attended with an economical effect. This arises from the smaller number of different tools required in making them, as well as from less frequent change in the adjustment of those tools. A similar economy prevails in the navy; by having ships divided into a certain number of classes, each of which comprises vessels of the same dimensions, the rigging made for one vessel will fit any of its class.

The effects of the removal of a monopoly are frequently important, and they were perhaps never more remarkable than in the bobbin-net trade, in the years 1824 and 1825. These effects were, however, considerably enhanced by the general rage for speculations which was so prevalent during that singular period. One of the patents of Mr. Heathcote for a bobbin-net machine had expired, whilst another, for an improvement in one part of such Machines, called a *Turn-again*, had yet a few years to run.

* 28*s*. per cwt. for the finer, 21*s*. per cwt. for the coarser papers.

Manu-
factures.

Many licenses had been granted to use the former Patent, which were charged at the rate of about five pounds per annum for each quarter of a yard in width, so that what is termed a six-quarter frame, one which makes bobbin-net a yard and a half wide, paid thirty pounds a year. Infringements of the second Patent having taken place, it was ultimately abandoned in August 1823.

Sect. I.

The bobbin-net Machine occupies little space, and is well adapted for a domestic Manufacture. It had also hitherto yielded very large profit; it is not therefore surprising that on the removal of the monopoly arising from this Patent, a multitude of persons became desirous of embarking in the trade. Those Machines which already existed were principally in the hands of Manufacturers; but a kind of mania seized on persons of all descriptions who could raise a small capital; and accordingly butchers, bakers, small farmers, publicans, gentlemen's servants, and, in some cases, clergymen, were anxious to possess bobbin-net Machines.

Bobbin-net
mania.

Some few Machines were rented; but in most of these cases the workman purchased the Machine he rented, by instalments of from three to six pounds weekly for a six-quarter Machine. Many individuals amongst these classes being unacquainted with the mode of using the Machines so purchased, paid others of more experience for instructing them in their use; fifty or sixty pounds were sometimes given for this instruction. The success of the first speculators at the commencement induced others to follow the example; and the Machine-makers were almost overwhelmed with orders for lace-frames. Such was the desire to procure them, that many persons deposited a large part, or the whole of the price in the hands of the Manufacturers, in order to ensure their having the earliest supply. This, as might naturally be expected, raised the price of wages amongst the operatives employed in Machine-making; and the effect was felt at a considerable distance from Nottingham, which was the centre of this mania. The effect was most remarkable upon the price of the wages of the persons employed in making these Machines.

Rent of
Machines.Rise in
wages.

Smiths not used to *flat filing* coming from distant parts earned from 30s. to 42s. per week. Finishing smiths, accustomed to the work, gained from 3l. to 4l. per week.

The forging smith, if accustomed to his work, gained from 5l. to 6l. per week, and some few earned 10l. per week.

In making what is technically called *insides*, those who were best paid were generally clock and watch-makers, from all the districts round, and who received from 3l. to 4l. per week.

The *setters up*, persons who put the parts of the Machine together, charged 20l. for their assistance; and a six-quarter Machine could be put together in a fortnight or three weeks. Good workmen were thus induced to desert less profitable branches of work in order to supply this extraordinary demand. The masters in other trades found their men leaving them without being aware of the immediate reason; some of the more intelligent traced out the cause, and went from Birmingham to Nottingham, in order to examine into the circumstances which had withdrawn almost all the journeymen clock-makers from their own workshops. It was soon apparent that the men who had

Manu-
factures.

been making clocks at Birmingham at the rate of 25s. a week could earn 2l. by working at lace-frame-making at Nottingham.

Reduction
in price of
bobbin-net.

Diminished
value of
Machines.

On examining the nature of this profitable work, the clock-makers perceived that one part of the bobbin-net Machines, that which held the bobbins, could be easily made in their own workshops. They, therefore, contracted with the Machine-makers, who had already more work ordered than they could execute, to supply the bobbin carriers at a price, which enabled them on their return home to give such increased wages as should retain their own workmen, as well as yield themselves a good profit. Thus an additional facility was afforded to the construction of these bobbin-net Machines. The conclusion was not difficult to be foreseen, the immense supply of bobbin-net thus poured into the market speedily reduced its price. The reduction in price rendered the Machines by which the net was made less valuable, some few of the earliest producers carried on a profitable trade for a short time, but multitudes were disappointed and many ruined. The low price at which the fabric sold, together with its lightness and beauty, combined to extend the sale, and ultimately new improvements in the Machines, rendered the older ones still less valuable.

Productive
power of a
lace-frame.

The bobbin-net trade is at present both extensive and increasing, and as it may probably at some future day claim a larger portion of public attention, it will be interesting briefly to describe its present state.

A lace-frame at the present day on the most improved principle manufacturing a piece of net two yards wide, when worked night and day, will produce 620 racks per week. A rack is 240 holes, and as in the Machine to which we refer three racks are equal in length to one yard, it will produce 21,493 square yards of bobbin-net annually. Three men keep this Machine constantly working, and they were paid by piece-work in 1830 about 25s. each. Two boys, working only in the day-time, will prepare the bobbins for this Machine; these latter are paid from 2s. to 4s. per week according to their skill. Forty-six square yards of this net weigh two pounds three ounces, so that each square yard weighs a little more than three-quarters of an ounce.

For a condensed and general view of the present state of this trade we shall avail ourselves of a statement by Mr. William Felkin of Nottingham, entitled *Facts and Calculations illustrative of the present State of the Bobbin-net Trade*, dated September 1831. It appears to have been collected with care, and contains in a single sheet of paper a body of facts of the greatest importance. We cannot omit the opportunity of expressing our hope that the example will be followed by other trades, and that we may by such means possess a body of information equally important to the capitalist and the operative.

The total capital employed in the factories for preparing the cotton, in those for weaving the bobbin-net, and in various processes to which it is subject, is estimated at above 2,000,000l. and the number of persons who receive wages, at above 200,000.

Manu-
factures.

Comparison of the Value of the Raw Material when Imported, with the Value of Manufactured Goods therefrom.

Sect. I.
Bobbin-net
trade.

"Amount of Sea Island cotton annually used 1,600,000 lbs. value 120,000*l.*; this is Manufactured into yarn, weighing 1,000,000 lbs. value 500,000*l.*

"There is also used 25,000 lbs. of raw silk, which costs 30,000*l.*, and is doubled into 20,000 lbs. thrown, worth 40,000*l.*

The cotton is worked into	6,750,000 sq. yds. of power net, worth 1 <i>s.</i> 3 <i>d.</i> per sq. yd.,	421,875 <i>l.</i>	{ Being on an average coarse 11-point, and nearly all in plain net.
	15,750,000 of hand 1 <i>s.</i> 9 <i>d.</i>	1,378,125	
	150,000 of fancy 3 <i>s.</i> 6 <i>d.</i>	26,250	{ Being on an average fine 11-point, and two-thirds in quillings.
The silk	750,000 of silk 1 <i>s.</i> 9 <i>d.</i>	65,625	

Square yards 23,400,000 annual produce of bobbin-net, of present value of 1,891,875*l.*

"The brown nets which are sold in the Nottingham market, are in part disposed of by the agents of twelve or fifteen of the larger makers, *i. e.* to the amount of about 250,000*l.* a year. The principal part of the remainder, *i. e.* about 1,050,000*l.* a year, is sold by about 200 agents, who take the goods from one warehouse to another for sale. Of course, many of these are of respectable character and competent to the task they undertake, and which from the amount of property just stated as annually passing through their hands, and the agent not usually giving up the name of the purchasers to his principals, is evidently a very responsible one. It is to be regretted, that the confidence of the Machine owners has not in some recent instances been justified by the conduct of those they employed. Long-continued series of forced sales, effected by some agents of bad character and habits, for the purpose of temporarily meeting the claims of those whose goods had been placed in their hands for sale, have very seriously and permanently affected the general prices of the market, eventually caused losses to the Machine owners, and reflected unmerited discredit on those of the commission agents who conduct their sales with business-like precision and integrity. Now that the smaller Machine owners' property in Machinery is become almost or entirely valueless, and the profits of all are reduced to what at least in this trade is an unusually low rate, it is surely very desirable to guard, by the exercise of increased caution, against frauds or irregularities, calculated so materially to prejudice both those who make bobbin-net and those who hold stocks of it, and the temptations to which are great in proportion to the ease and secrecy by which they may be effected and for a time carried on.

"Of this production, about half is exported in the unembroidered state, and in the white principally; yet a large quantity is sent in the unbleached state, and is embroidered abroad, and much is figured in the white on the Continent. So that it is probable that as much is figured abroad as at home, and this principally on account of wages being lower there than here, notwithstanding the low rate of embroiderers' earnings in this Country. This foreign embroidery is chiefly done in Belgium, Saxony, and until recently, Poland. The exports of bobbin-net are in great part to Hamburgh, for sale at home and at Leipzig and Frankfort fairs, Antwerp, and the rest of Belgium; to France, by contraband; Italy, and North and South America. Though a very suitable article, yet the quantity sent Eastward of the Cape of Good Hope has hitherto been too trifling for notice. Three-eighths of the whole production is sold unembroidered at home. The remaining one-eighth is embroidered in this Country, and increases the ultimate value as under, *viz.*

Embroidery on power net increases value	131,840 <i>l.</i> , and is ultimately worth	553,715 <i>l.</i>
Ditto on hand	1,205,860	2,583,985
Ditto on fancy	78,750	105,000
Ditto on silk	109,375	175,000

Total embroidery wages and profit 1,525,825*l.* Ultimate total value. . 3,417,700*l.*

"From this it appears, that in the operations of this trade, which had no existence twenty years ago, 120,000*l.* original cost of cotton, becomes when Manufactured, of the ultimate value of 3,242,700*l.* sterling.

"There are about seventy houses engaged chiefly in embroidering goods, and about seventy houses engaged

Manu-
factures.

" in the preparation and sale of plain goods principally. The *cash* paid to small owners, for the purchase of hand
 " nets, about equals the amount of capital created by the credit given in this market by power net Manufac-
 " turers.

Sect. I.

" As to weekly wages paid, I hazard the following as the judgment of those conversant with the respective
 " branches, viz.

" In fine spinning and doubling: adults, 25s.; children, 7s.; work twelve hours per day.

" In bobbin-net making: men working Machines, 18s.; apprentices, youths of fifteen or more, 10s.; by power,
 " fifteen hours; by hand, eight to twelve hours, according to width.

" In mending: children, 4s.; women, 8s.; work nine to fourteen hours, *ad libitum*.

" In winding, threading, &c.: children and young women, 5s.; irregular work, according to the progress of
 " Machines.

" In embroidery: children, seven years old and upwards, 1s. to 3s.; work ten to twelve hours; women, if
 " regularly at work, 5s. to 7s. 6d.; twelve to fourteen hours.

" As an example of the effect of the wages of lace embroidery, &c. it may be observed, it is often the case
 " that a stocking weaver in a country village will earn only 7s. a week, and his wife and children 7s. to 14s.
 " more at the embroidery frame."

The principal part of the hand Machines are worked in shops, forming part of, or
 attached to private houses. The subjoined list will show the kinds of Machinery em-
 ployed, and classes of persons to whom it belongs.

Bobbin-net
Machines
and their
proprietors
classed.*Bobbin-net Machinery now at work in the Kingdom.*

Hand Levers,	6-quarter	500	700 persons own 1 machine -	700 machines
	7-quarter	200	226	2 - 452
	8-quarter	300	181	3 - 543
	10-quarter	300	96	4 - 384
	12-quarter	30	40	5 - 200
	16-quarter	20	21	6 - 126
	20-quarter	1	17	7 - 119
		1350	19	8 - 152
Hand Rotary,	10-quarter	50	17	9 - 153
	12-quarter	50	12	10 - 120
		100	8	11 - 88
Hand Circulars,	6-quarter	100	6	12 - 72
	7-quarter	300	5	13 - 65
	8-quarter	400	5	14 - 70
	9-quarter	100	4	16 - 64
	10-quarter	300	25 own respectively 18, 19, 20,	
	12-quarter	100	21, 23, 24, 25, 26, 27, 28,	
		1300	29, 30, 32, 33, 35, 36, 37,	
Hand Traverse, Pusher, Straight			50, 60, 68, 70, 75, 95, 105,	
Bolt, &c. averaging 5-quarters		750	206 1192	
Total hand Machines		3500		
Power	6-quarter	100	Number of owners of	
	7-quarter	40	Machines 1382	
	8-quarter	350	Holding together 4500 Machines.	
	10-quarter	270		
	12-quarter	220	The hand workmen consist of the above-named	
	16-quarter	20	owners..... 1000	
Total power Machines		1000	And of journeymen and apprentices..... 4000	
Total number of Machines		4500		

5000

These Machines are distributed as follows :

Nottingham	1240
New Radford	140
Old Radford and Blooms Grove	240
Ison Green	160
Beeston and Chilwell	130
New and Old Snenton	180
Derby and its vicinity	185
Loughborough and its vicinity	385
Leicester	95
Mansfield	85
Tiverton	220
Barnstable	180
Chard	190
Isle of Wight	80
In sundry other places	990
	4500

"Of the above owners, 1000 work in their own Machines, and enter into the class of journeymen as well as masters in operating on the rate of wages. If they reduce the price of their goods in the market, they reduce their own wages first, and, of course, eventually the rate of wages throughout the trade.—It is a very lamentable fact, that one-half, or more, of the 1100 persons specified in the list as owning one, two, and three Machines, have been compelled to mortgage their Machines for more than their worth in the market, and are in many cases totally insolvent. This has chiefly arisen from the fall in prices of nets beyond the reduction in prices of cotton and wages. This class of persons having become indebted to the cotton Merchant, have been compelled to pay a comparatively excessive price for the thread they have used, and to sell their goods at the lowest prices of the market. Besides, their Machines are principally narrow and making short pieces, while the absurd system of bleaching at so much a piece goods of all lengths and widths, and dressing at so much all widths, has caused the new Machines to be all wide and capable of producing long pieces, and of course to the serious disadvantage, if not utter ruin, of the small owner of narrow Machines.

"It has been observed above, that wages have been reduced, say 25 per cent. in the last two years, or from 24s. to 18s. a week. Machines have increased in the same time one-eighth in number, or from 4000 to 4500, and one-sixth in capacity of production. It is deserving the serious notice of all proprietors of existing Machines, that Machines are now introducing into the trade of such power of production as must still more than ever depreciate (in the absence of an immensely increased demand) the value of their property, have a direct tendency to sink the small owners into journeymen, and either greatly increase the labour, or depreciate the workman's wages. It is a curious fact, as illustrative of the progress of Machinery, that there are bobbin-net Machines, which, being worked by three men, six hours each or eighteen hours per day, are turning off 20,000 square yards of good net per annum. Now it is not to be fairly denied, that such Machines being multiplied to some extent, must, with only the actual demand, lower even the present trifling value of the 1600 or 1700 narrow hand Machines, one half or more, and reduce the rate of wages of those who work in them one-third, and that of the remaining hand Machine workmen at least one-fourth; or, which is the same thing, compel them to increase their labour in the same proportion."

From this abstract we may form some judgment of the importance of the bobbin-net trade. But the extent to which it bids fair to be carried when the Eastern markets shall be more open to our industry, may be conjectured from the fact which Mr. Felkin states,—that "We can export a durable and elegant article in cotton bobbin-net at 4d.

Manu-
factures.

“per square yard, proper for certain useful and ornamental purposes, as curtains, &c. ; Sect. 1.
 “and another article used for many purposes in female dress at 6d. the square yard.”

Patents.

In order to encourage the importation, the improvement, or the invention of Machines and discoveries relating to Manufactures, it has been the practice in many Countries to grant to the first introducers an exclusive privilege for a term of years. Such monopolies are termed Patents, and are granted on the payment of certain fees for different periods from five to twenty years.

Their ex-
pense.

The following Table, compiled from the Report of the Committee of the House of Commons on Patents, 1829, shows the Expense and Duration of Patents in various Countries.

	Expense.	Term of Years.	Number granted in six years, end- ing in 1826.— (Rep. p. 243.)
	£		
England.....	120	14	914
Ireland	125	14	
Scotland.....	100	14	
America.....	6 15s.	14	
	{ 12	5	1091
France.....	{ 32	10	
	{ 60	15	
Netherlands.....	6 to £30	5, 10, 15	
Austria.....	42 10s.	15	1099
Spain..... Inventor..	20 9s. 4d.	15	
Improver ..	12 5s. 7d.	10	
Importer..	10 4s. 8d.	6	

It is clearly of importance to preserve to each inventor the sole use of his invention, until he shall have been amply repaid for the risk and expense to which he has been exposed, as well as for the talent he has exerted. But the degrees of merit are so numerous, and the difficulties of legislating upon the subject are so great, that it has been found practically to be almost impossible to frame a law which shall not be open to the most serious objections.

The difficulty of defending an English Patent in any judicial trial has been found to be very great, and the number of instances on record in which the defence has succeeded are comparatively few. This circumstance has induced some Manufacturers no longer to regard a Patent as a privilege by which a monopoly price may be secured; but they sell the Patent article at such a price as will merely produce the ordinary

* The expense of a Patent in Spain is stated in the Report to be respectively 2000, 1200, and 1000 reals. If these are reals of *Vellon*, in which accounts are usually kept at Madrid, the above sums are correct; but if they are reals of *Plate*, then the above sums ought to be nearly doubled.

Manu-
factures. profits of capital, and thus secure to themselves the fabrication of it, because no competitors can derive a profit from invading a Patent so exercised. Sect. I.

Amongst the restrictions intended for the general benefit of our Manufacturers, there existed one by which workmen were forbidden to go out of the Country. A law so completely at variance with every principle of liberty ought never to have been enacted. It was not, however, until experience had convinced the Legislature of its inefficiency that it was repealed. When the intercourse between England and the Continent became extensive, it was soon found that it was impossible to discover the various disguises which could be assumed, and the effect of the law was rather to deter by the fear of punishment the workmen who had left the Country from returning, than to prevent their disposition to migrate.

ON THE EXPORTATION OF MACHINERY.

Not only were workmen prohibited by Act of Parliament from transporting themselves to a Country in which their industry would produce for them higher wages, but it was forbidden to export the greater part of the Machinery which they were employed to make at home. The reason of this prohibition was, that foreigners might not avail themselves of our improved Machinery, and thus compete with our Manufacturers. It was, in fact, a sacrifice of the interests of one class of persons, the makers of Machinery, for that of another class, those who use it. Now, independently of the impolicy of interfering unnecessarily between them, it may be observed, that the first class, or the makers of Machinery, are, as a body, far more intelligent than those who only use it; and although, at present, they are not nearly so numerous, yet, if the prohibition which cramps their ingenuity were removed, there appears good reason to believe that their number would be greatly increased, and that it might, in time, surpass that of those who use Machinery.

The advocates of such prohibitions seem to rely greatly upon the possibility of preventing the knowledge of new contrivances being conveyed from one Country to another, and they also appear to take too limited a view of the possible, and even probable, improvements in Mechanics. For the purpose of examining the question, we will consider the case of two Manufacturers of the same article, one situated in a Country in which labour is very cheap, the Machinery very bad, and the modes of transport slow and expensive; the other engaged in Manufacturing in a Country in which the price of labour is very high, the Machinery very excellent, and the means of transport expeditious and economical. Let them both send their produce to the same market, and let each receive such a price as shall give to him the profit ordinarily produced by capital in his own Country. It is almost certain that in such circumstances the first improvement in Machinery will occur in the Country which is most advanced in civilization, because even admitting that the ingenuity to contrive were the same in the two Countries, the means of execution are very different. The effect of any improved Machinery in the rich Country will be perceived in the common market by a small fall in the price of the Manufactured article. This will be the first intimation to the Manufacturer of the poor

Comparative view
of improvement of
Machines in
a rich and a
poor Country.

Manu-
factures.

Sect. I.

Country, who will endeavour to meet this diminution in the selling price of his article by increased industry and economy in his factory, but he will soon find that this remedy is temporary, and the market-price is still falling. This will induce him to examine the rival fabric, in order to detect by its structure any improved mode of making it. If, as would most usually happen, he should be unsuccessful in this attempt, he will be forced to endeavour to contrive some improvement in his Machinery, or to acquire information respecting that which has taken place in the factories of the rich Country. Perhaps after an ineffectual attempt to attain by letters the information he requires, he sets out to visit the factories of his rivals. To a foreigner and rival Manufacturer such establishments are not easily accessible, and the more recent the improvement, the less likely he will be to gain access to them. His next step will be to acquire a knowledge of them from the workmen employed in using or making the Machines. Without Drawings or an examination of the Machines themselves, this process will be a slow and tedious one, and he will be liable after all to be deceived by artful and designing workmen, and be exposed to many chances of failure. But suppose he returns to his own Country with perfect Drawings and instructions he must then begin to construct his improved Machines: these cannot be executed by him either so cheaply or so well as they are in the richer Country; but after the lapse of some time, let us suppose them to be in working order.

Let us now consider what will have occurred to the Manufacturer in the rich Country, even supposing that during the whole of this time he has made only one step. He will, in the first instance, have realized a profit by supplying the home market at the usual price with an article which it costs him less to produce; he will then reduce the price both in the home and foreign market in order to produce a more extended sale. It is in this stage that the Manufacturer in the poor Country first feels the effect of the competition; and if we suppose that from the first application of the new improvement in the rich Country, and the commencement of its employment in the poor Country only two or three years elapse, yet will the Manufacturer who contrived the improvement have realized so large a portion of the outlay which it rendered necessary, that he will now be in a state to make a much greater reduction in the price of his produce, and thus render the gains of his rivals quite inferior to those which his own ingenuity had produced for himself.

It is contended that by admitting the exportation of Machinery, foreign Manufacturers will be supplied with Machines equal to our own. Now the first answer which presents itself is supplied by almost the whole of the present Essay, *viz. That in order to succeed in a Manufacture, it is necessary not merely to possess good Machinery, but that the domestic economy of the factory should be most carefully regulated.*

The truth, as well as the importance of this principle is so well established in the Report of a Committee of the House of Commons "On the Export of Tools and Machinery," that we shall avail ourselves of the opinions and evidence there stated before we offer those additional observations which have occurred to our own experience.

Manu-
fact-
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Sect. I.

Report of
House of
Commons
on Export
of Tools
and Ma-
chinery.

"Supposing, indeed, that the same Machinery which is used in England could be obtained on the Continent, it is the opinion of some of the most intelligent of the witnesses that the want of arrangement in foreign Manufactories, of division of labour in their work, of skill and perseverance in their workmen, and of enterprise in the masters, together with the comparatively low estimation in which the master Manufacturers are held on the Continent, and with the comparative want of capital, and of many other advantageous circumstances detailed in the evidence, would prevent foreigners from interfering in any great degree by competition with our principal Manufacturers; on which subject the Committee submit the following evidence as worthy the attention of the House:

'I would ask whether, upon the whole, you consider any danger likely to arise to our Manufactures from competition, even if the French were supplied with Machinery equally good and cheap as our own?—They will always be behind us until their general habits approximate to ours; and they must be behind us for many reasons that I have before given.

'Why must they be behind us?—One other reason is, that a cotton Manufacturer who left Manchester seven years ago, would be driven out of the market by the men who are now living in it, provided his knowledge had not kept pace with those who have been during that time constantly profiting by the progressive improvements that have taken place in that period; this progressive knowledge and experience is our great power and advantage.'

"It should also be observed, that the constant, nay almost daily, improvements which take place in our Machinery itself, as well as in the mode of its application, require that all those means and advantages alluded to above, should be in constant operation; and that, in the opinion of several of the witnesses, although Europe were possessed of every tool now used in the United Kingdom, along with the assistance of English artisans, which she may have in any number, yet from the natural and acquired advantages possessed by this Country, the Manufacturers of the United Kingdom would for Ages continue to retain the superiority they now enjoy. It is indeed the opinion of many, that if the exportation of Machinery were permitted, the exportation would often consist of those Tools and Machines which, although already superseded by new inventions, still continue to be employed from want of opportunity to get rid of them, to the detriment, in many instances, of the Trade and Manufactures of the Country; and it is matter worthy of consideration, and fully borne out by the evidence, that by such increased foreign demand for Machinery, and the ingenuity and skill of our workmen would have greater scope, and that, important as the improvements in Machinery have lately been, they might, under such circumstances, be fairly expected to increase to a degree beyond all precedent.

"The many important facilities for the construction of Machines and the Manufacturing of commodities which we possess, are enjoyed by no other Country, nor is it likely that any Country can enjoy them to an equal extent for an indefinite period. It is admitted by every one that our skill is unrivalled; the industry and power of our people unequalled; their ingenuity, as displayed in the continual improvement of Machinery and production of commodities, without parallel, and apparently without limit. The freedom which, under our Government, every man has to use his capital, his labour, and his talents, in the manner most conducive to his interests, are inestimable advantages; canals are cut, and rail-roads constructed, by the voluntary association of persons whose local knowledge enables them to place them in the most desirable situations; and these great advantages cannot exist under less free Governments. These circumstances, when taken together, give such a decided superiority to our people, that no injurious rivalry either in the construction of Machinery or the Manufacture of commodities can reasonably be anticipated."

It would appear, also, that there are circumstances which show that the immediate exportation of improved Machinery is not quite so certain, and that the powerful principle of self-interest will urge the makers of Machinery to push its extension in a different direction.

When a great maker of Machinery has contrived a new Machine for any particular

Manu-
factures.
Makers of
Machines
sometimes
invent im-
provements.

Sect. I.

process, or has made some great improvement on those in common use, to whom will he naturally apply for the purpose of selling his new Machines? Undoubtedly, in by far the majority of cases, he will communicate the circumstance to his nearest and best customers, those to whom he has immediate and personal access, and whose capability to fulfil any contract is best known to him. He will communicate with them, and offer to take their orders for the new Machine, nor will he think of writing to inform foreign customers so long as he finds the whole force of his establishment insufficient to supply the home demand. Thus then the Machine-maker is himself interested in giving the first advantage of any new improvement to his own Countrymen.

The class of operatives who make Machinery possess much more skill, and are paid much more highly than that class who merely use it, and if a free exportation of Machinery were allowed, this higher and more valuable class would undoubtedly be greatly increased. For, notwithstanding the high price of wages, there is no Country in which Machinery can at this moment be made either so well or so cheaply as in England. We might, therefore, supply the whole World with Machinery, at an evident advantage both to ourselves and our customers. In Manchester, and the districts round about, thirty thousand men are employed in Manufacturing the Machinery which gives employment in the same district to hundreds of thousands of operatives. The time can yet be remembered by some, when the number of the whole population engaged in the cotton-trade of that district did not exceed that of those now employed in making the Machines the present population use. Hence, then, if England should ever become a great exporter of Machinery, she would necessarily contain a large class of workmen to whom skill would be indispensable, and, consequently, to whom high wages would be paid; and her Manufacturers would be fewer in numbers, but they would undoubtedly have the advantage of being the first to derive profit from improved Machinery. Under such circumstances any diminution of demand in Machinery would, in the first instance, be felt by a class much better able to meet it, than the class which now suffers upon every check in the consumption of our Manufactured goods; and the resulting misery would therefore assume a mitigated character.

Objections
to exporta-
tion.

The objections to which the exportation of Machinery is liable, arise from the anticipation that the demand of the World is not sufficient to give occupation to a large proportion of the operatives of one Country more favourably circumstanced than all others for exercising that trade. It is also feared that when other Countries have purchased our Machines, they will cease to demand new ones. On the first of these objections it may be observed that, in point of fact, we have not at present sufficient workmen in that line of employment to supply much beyond the home demand for Machinery, and that the demand would increase by degrees, and workmen be produced in consequence of it. To the other objection, the statement we have given of the usual progress in the improvements of the Machinery employed in any kind of Manufacture, and the average duration of it not arising from wear and tear, but from its being superseded, is a complete reply.

If our customers did not adopt the new Machinery contrived by us as soon as they

Manu-
factures.

Sect. I.

could procure it, then our own Manufacturers would extend their establishments, and undersell their rivals in their own markets. It may also be urged, that in each kind of Machinery a maximum of perfection may be imagined beyond which it is impossible to advance. The last advances are usually the smallest when compared with those which precede them; but it should be observed, that they generally occur when the number of Machines in employment is already large, and consequently their effects upon the power of producing are very considerable. Although it should be admitted that any individual species of Machinery may arrive after a long period at a degree of perfection which would render further improvement nearly hopeless, yet it is impossible to suppose that this can be the case with all kinds of Mechanism. The limit of improvement is rarely approached, except in extensive branches of National Manufactures, and the number of such branches is even at present very small.

The productions of Nature, varied and numerous as they are, may each, in some future day, become the basis of extensive Manufactures, and give life, employment, and wealth to millions of Human beings. But the crude treasures perpetually exposed before our eyes contain within them other and more valuable principles. All these, in their innumerable combinations, which Ages of labour and research can never exhaust, may be destined to furnish, in perpetual succession, the sources of our wealth and of our happiness. Science and Knowledge are subject, in their extension and increase, to laws quite opposite to those which regulate the Material World; unlike the laws of Molecular Attraction, which cease at sensible distances, or that of Gravity, which decreases rapidly with the increasing distance from the point of its origin, the further we advance from the origin of our Knowledge, the larger it becomes, and the greater power it bestows upon its cultivators to add new fields to its dominions. Yet does this continually and rapidly increasing power, instead of giving us any reason to anticipate the exhaustion of so fertile a field, place us at each advance on some higher eminence, from which the mind contemplates the past, and feels irresistibly convinced that the whole already gained bears a constantly diminishing ratio to the still more rapidly expanding horizon of our Knowledge. But if the knowledge of the Chemical and Physical properties of the bodies which surround us, as well as that of the less tangible elements, Light, Electricity, and Heat, which mysteriously modify or change their combinations, all concur to convince us of the same fact; we must remember that another and a higher Science, itself still more boundless, is also advancing with a Giant's stride, and having grasped the mightier masses of the Universe, and reduced their wanderings to laws, has given to us in its own condensed language expressions, which are to the past as History, to the future as Prophecy. It is the same Science which is now preparing its fetters for the minutest atoms which Nature has created: already it has nearly chained the ethereal fluid, and bound in one harmonious system all the intricate and splendid phenomena of Light. It is the Science of *Calculation*, which becomes continually more necessary at each step of our progress, and which must ultimately govern the whole of the applications of Science to the Arts of life.

Unlimited
supply from
Nature of
objects of
Manufac-
ture.Prospects
for the
future.

But perhaps a doubt may arise in the mind whilst contemplating the continually

Manu-
factures.

Human
force may
be insuffi-
cient when
coal-fields
fail.

Heat may
be supplied
from volca-
nic districts.

increasing field of Human Knowledge, that the weak arm of man may want the physical force requisite to render that knowledge available. The experience of the past has stamped with the indelible character of truth the maxim that "*Knowledge is Power.*" It not merely gives to its votaries control over the mental faculties of their species, but it is the generator of physical force. The discovery of the expansive power of steam, its condensation, and the doctrine of latent heat, has already added to the population of this small island millions of hands. But the source of this power is not without limit, and the coal-mines of the World may ultimately be exhausted. Without adverting to the theory that new formations of that mineral are now depositing under the sea, at the estuaries of some of our larger rivers; without anticipating the application of other fluids requiring a less supply of caloric than water;—we may remark that the sea itself offers a perennial source of power hitherto almost unapplied. The tides, twice in each day, raise a vast mass of water, which might be made available for driving Machinery. But supposing heat still to remain necessary when the exhausted state of our coal-fields renders it expensive. Long before that period arrives, other methods will probably have been invented for producing it. In some districts there are springs of hot water, which have flowed for centuries unchanged in temperature. In many parts of the island of Ischia, by deepening the sources of the hot springs but a few feet, the water boils, and there can be little doubt that, by boring a short distance, steam of high pressure would issue from the crifice: here then is a natural source of heat, one which is extensively spread over the Globe, since it occurs near all active volcanoes. Whether the abstraction of heat on a large scale might not have the effect of diminishing the frequency or the intensity of their eruptions, and whether such Countries may not ultimately be destined to become the great centres of the Manufactures of the World, must be decided by time and circumstances.

CONCLUSION.

Having now completed the view we proposed to take of the general principles which regulate the successful application of Mechanical Science to great establishments for the production of Manufactured goods, it remains for us to suggest a few inquiries, and to offer a few observations to those whom an enlightened curiosity may lead to examine the factories of this or of other Countries.

The first remark applies to almost all inquiries, *viz.* that *it is important to commit to writing, all information as soon as possible after it is received, especially when numbers are concerned.*

Necessity of
writing
down infor-
mation on
the spot.

It is frequently impossible to do this when visiting an establishment, and where not even the slightest jealousy exists; the mere act of writing information as it is communicated orally, is a great interruption to the examination of Machinery. In such cases, therefore, it is advisable to have prepared beforehand the questions to be asked, and to leave blanks for the answers, which may be quickly inserted, as they are in a multitude of cases merely numbers. Those who have not tried this plan will be surprised at the quantity of information which may be acquired through its means, even by a short examination.

Manu-
factures.

Sect. I

Each Manufacture requires its own list of questions, which will be better drawn up after the first visit. The following outline, which is very generally applicable, may suffice for an illustration; and to save time it may be convenient to have it printed, and to bind up in the form of a pocket-book, a hundred copies of the skeleton forms for processes, with about twenty of the general inquiries.

GENERAL INQUIRIES.

Outlines of a Description of any of the Mechanical Arts ought to contain information on the following points.

Brief sketch of its history, particularly the date of its invention and its introduction into England.

Short reference to the previous states through which the material employed has passed; the places whence it is procured; the price of a given quantity.

The various processes must now be described successively according to the plan (B); after which the following information should be given:

Are various kinds of the same article made in one establishment, or at different ones, and are there differences in the processes?

To what defects are the goods liable?

What substitutes or adulterations are used?

What waste is allowed by the master?

What tests are there of the goodness of the Manufactured article?

The weight of a given quantity, or number, and a comparison with that of the raw material.

The wholesale price at the Manufactory, £. s. d. per

The usual retail price, £. s. d. per

Who provide tools? Master, or Men. Who repair tools? Master, or Men.

What is the expense of the Machinery?

What is the annual wear and tear, and what its duration?

Is there any particular trade for making it? Where?

Is it made and repaired at the Manufactory?

In any Manufactory visited, state the number () of processes, and of persons employed in each process, and the quantity of Manufactured produce.

What quantity is made annually in Great Britain?

Is the capital invested in Manufactories large or small?

Mention the principal seats of this Manufacture in England; and if it flourishes much abroad, the places where it is established should be mentioned.

The duty, excise, or bounty, if any, should be stated; and any alterations in past years; and also the amount exported or imported for a series of years.

Whether the same article, but of superior or inferior make, is imported.

Does the Manufacturer export, or sell, to a middle-man, who supplies the merchant?

To what Countries is it chiefly sent—and in what goods are the returns made?

Each process requires a separate skeleton, and the following outline will be sufficient for many different Manufactories.

Manu-
factures. Process () Manufacture () Place () Name () Sect. I.
date 183

The mode of executing it, with sketches of the tools or Machine if necessary.

The number of persons necessary to attend the Machine.

Are the operatives men, () women, () or children? () If mixed, what are the proportions?

What is the pay of each? (s. d.) (s. d.) (s. d.) per

What number () of hours do they work per day?

Is it usual, or necessary, to work night and day without stopping?

Is the labour performed by piece or by day-work?

Who provide tools? Master, Men. Who repair tools? Master, Men.

What degree of skill is required, and how many years' () apprenticeship?

The number of times () the operation is repeated per day or per hour.

The number of failures () in a thousand.

Whether the workman or the master loses by the broken ones?

What is done with the broken ones?

If the same process is repeated several times, state the diminution or increase of measure, and the loss, if any, at each time.

Use of the
skeletons.

In using this skeleton, the answers to the questions are in some cases printed as, Who repair the tools? Masters, Men; in order that the proper answer may be underlined with a pencil. In filling up the answers which require numbers, some care should be taken; for instance, if the observer stands with his watch in his hand before a person heading a pin the workman will almost certainly increase his speed, and the estimate will be too large. A much better average will result from inquiring what quantity is considered a fair day's work. When this cannot be ascertained, the number of operations performed in a given time may frequently be ascertained, when the workman is quite unconscious that any person is observing him. Thus the sound made by the motion of a loom may enable the observer to count the number of strokes per minute, even though he is outside the building in which it is contained.

It frequently happens that in a series of answers to such questions, there are some which, although given directly, may also be deduced by a short calculation from others that are given or known, and advantage should always be taken of these verifications in order to confirm the accuracy of the statements, or in case they are discordant, to correct the apparent anomalies. In putting lists of questions into the hands of a person undertaking to give information upon any subject, it is in some cases desirable to have an estimate of the soundness of his judgment. The questions can frequently be so shaped that some of them may indirectly depend on others, and one or two may be inserted whose answers can be obtained by other methods; nor is this process without its advantages in enabling us to determine the value of our own judgment. The habit of forming an estimate of the magnitude or frequency of any object immediately previous to our applying to it measure or number, tends materially to fix our attention and to improve our judgment.

MANUFACTURES.

PART I.

MACHINERY.

**Manufac-
tures.** (1.) IN order to follow out the plan sketched in the preceding Introductory Chapter, it is necessary, before we proceed to describe the processes of different Manufactories, that we should explain and illustrate the fundamental principles of the Machines by which these processes are conducted, and also such simple Machines as are of common application and use; for it is obvious that unless these are properly understood in their simple forms, it will be impossible to comprehend their operation in the complicated and combined forms in which they are employed in the various Manufactories we shall have to describe.

**Definition
of a Ma-
chine.** Amongst the Ancients, the term Machine was applied to every tool or instrument employed in the performance of any work; with us it is more restricted, but it is still of uncertain application; the best definition of Machine, as it relates to manufacturing processes, seems to be, that it is a construction combining different mechanical powers with a view to the production of some ulterior and definite object, and is, except so far as custom has in a few cases made a sort of distinction, synonymous with Engine. The English, for instance, always say Steam-engine, but the French call this a Machine, *Machine à vapeur*. In fact, there are a number of cases in which Machine or Engine is used with perfect indifference; as for example, Planing Engine or Planing Machine, Boring Engine or Boring Machine, Dividing Engine or Dividing Machine, &c. The same definition may therefore be applied both to Engine and to Machine, the application of one term or the other being rather a matter of custom than expressive of an intrinsic difference, in those cases where the one or the other is employed.

The object intended to be effected in every Machine is to transmit a certain power or force applied on one part, called the applied point, to another part, called the working point, in order there to produce some mechanical operation. We shall first, therefore, inquire into the nature of those forces or powers by which motion is communicated, generally designated *motive forces*; secondly, of those which, from the imperfect nature of Machinery, have a tendency to counteract and impede this motion, called therefore *retarding forces*; and lastly, of those which are introduced to modify and regulate the motion resulting from the variable difference of the two former, and which may therefore be termed *regulating forces*.

I. OF MOTIVE FORCES.

**First
movers.** *Motive forces or first movers may be divided into the following five classes:*

1. The muscular power of men.
2. The muscular power of horses and other animals.
3. The power or force of the wind.
4. The weight and moving force of water.
5. The expansive force and rapid condensation of steam.

(2.) In order to form a comparison between the effects **Machinery** produceable from these different sources of motion, it is at least convenient, if not necessary, to have one common **Dynamic** standard of reference, or one definite dynamic unit. In **unit.** this Country we employ what is called a *horse-power*, and it was perhaps at first intended to represent the medium effort of a horse. Several recent experiments, however, some of which were attended by the writer of this Essay, prove most distinctly that the nominal horse-power very far exceeds the actual power of the strongest horse, to continue working day by day, and much more the medium power of horses in general. This however is immaterial, so that the amount of what **Horse-
power.** is called a horse-power is properly understood. The horse-power, then, may be defined to be a force, from whatever source it arises, which is competent to raise 33,000 pounds one foot high in a minute, or more precisely, a force such that the weight raised by it in a minute, multiplied by the number of feet to which it is raised, shall produce the above number, 33,000, abstracting from every kind of resistance but the load itself. This distinction leads us to another consideration, namely, the maximum power of a horse for useful mechanical effect. When we state that 33,000 pounds raised a foot high in a minute is a horse-power, it is obvious that to raise this power unaided by Machinery is inconsistent with the muscular power of the animal; on the other hand, to raise 1 pound to the height of 33,000 feet is inconsistent with his speed. The number 33,000 must therefore be divided into two factors, one representing the weight in pounds and the other the number of feet per minute he is able to raise it, so that the product of the two may bring out the number required, and such that both the weight and speed may be best adapted to the power of the animal.

It has been ascertained from a number of well-directed experiments, that the speed at which a horse can move, so as to produce the maximum mechanical effect, is $2\frac{1}{2}$ English miles per hour, or 220 feet per minute; at which rate, taking the horse-power at what is above stated, he will constantly oppose a resistance or weight of 150 pounds; but from observations made on the resistance of canal boats, which are frequently drawn at about the rate of $2\frac{1}{2}$ miles an hour, it does not appear that a horse can be advantageously opposed to more than 100 pounds; and moreover, that being opposed to that resistance and moving with the velocity of $2\frac{1}{2}$ miles per hour, or 220 feet per minute, or $3\frac{2}{3}$ feet per second, the best effect is produced. It appears, therefore, that the actual medium power of a horse does not exceed 22,000 pounds a foot high in a minute.

(3.) In order to show the great economy in the employment of horses by adjusting the speed and weight to the nature of the animal's physical powers, we may take the case of our quick day-coaches; in these it is well known that proprietors consider it necessary to employ a horse

Manufac-
tures.

Horse-la-
bour in day-
coaches.

per mile, to horse the coach to and fro—that is, for a distance of 80 miles, eighty horses are employed or provided; for 100 miles one hundred horses; and so on; so that actually, taking rests into account, each horse travels but 8 miles per day. Again, the mean weight of such coaches, including passengers and luggage, is estimated at about 4200 pounds, and the resistance of our best turnpike roads is about one-thirtieth of the weight drawn, (Leslie's *Elements*, p. 253.) so that the force requisite to overcome the resistance of such a coach is 140 pounds; to effect this we have four horses; consequently, each horse has to exert a force of 35 pounds. We may therefore take 35 pounds $\times$ 8 miles = 280, as the measure of a horse's power for the day, when travelling at the rate of 10 miles per hour, whereas by reducing the speed to $2\frac{1}{2}$ miles per hour, the horse will be able to draw 100 pounds, and to continue his labours for 8 hours, or for 20 miles. We have therefore for a measure of his day's work at this rate 100 pounds $\times$ 20 miles = 2000, which is more than 7 times the mechanical effect produced at 10 miles per hour. In the case we here have taken of a quick stage-coach, this loss of power for the sake of gaining speed is unavoidable, but in a horse-mill, where we have it in our power to choose the speed, the advantage of attending to the capability of the animal is sufficiently obvious. For more on this subject, see the Chapter on RAILWAYS.

Comparison
of the nomi-
nal and ac-
tual horse-
power.

Having made these few remarks on the dynamic unit selected by English engineers, and on the excess of that unit beyond the unit it professes to represent, we may point out how much an engine denominated by horse-powers, when worked by steam, water, &c. exceeds the number of horses that must be employed to perform the same work in 24 hours, working night and day. To take as an example, a 10-horse-power engine, we have seen that the artificial horse-power here taken is expressed by 33,000; that the actual medium power of a horse must not be taken, when working to the best advantage, at more than 22,000; that the former will continue working twenty-four hours, and the latter only eight hours, and we shall then have the following numbers to express the relative effects, viz. for the engine 33,000 pounds $\times$ 24 hours $\times$ 10 horses = 7,920,000, and in the other case where horses are actually employed, 22,000 pounds $\times$ 8 hours $\times$ 10 horses = 1,760,000; whence as 176 : 792 :: 10 : 45. Consequently, if a steam-engine of 10 horses nominal power were kept at work day and night, it would require 45 horses to perform the same work in the same time; and making every allowance for stoppages, oiling, packing, &c. every nominal horse-power in a steam-engine is equivalent to four horses when working night and day, to two horses when working twelve hours per day, and equal to $1\frac{1}{2}$ horse when working eight hours per day. This will be an important consideration when we shall have to consider economy in the due selection of first movers.

In thus defining and illustrating the dynamic unit, or horse-power, we have been led to enter upon the amount of an actual horse-power, whereas to have proceeded regularly, we ought to have spoken first of the power of men; the transposition was however in some measure unavoidable.

Mechanical
power of
men.

(4.) *Of the power of men as first movers.*—Experiments have been made by Desaguliers, Smeaton, and others to determine the power of a man when employed as a mere source of mechanical action. Of course there will be a great variety of results in such experiments, because

men differ much from each other, not only in their absolute muscular power, but in their capability of exerting it in different ways. One man at a winch may be capable of an exertion far greater than another; but set these same two men to row in a boat, and the case may be reversed. Again, where the distance passed over forms a part of the effort, as in the case of men employed to remove sand or soil from one place to another, we shall find men excelling here who have but inferior power in either of the cases above named. Consequently we can hardly expect any very definite measure of a man's strength when considered as a mere source of mechanical power. It has, however, been decided by Smeaton, from a mean of several comparisons, that five good English labourers are about equivalent to the power of one horse. This must, however, be understood as the actual and not the nominal unit, therefore the power of a man may be stated to be such as is capable of raising 4400 pounds one foot high in a minute, or 30 pounds to the height of 146 feet in a minute. The writer of this Essay is aware that this is less than is sometimes stated to express the power of a man, but the experiments of Smeaton having fixed the ratio between the actual power of a man and horse at 1 to 5, and the power of the horse having been found to amount but to 22,000 pounds, that of the man will be no more than is above stated. Indeed, Smeaton himself, in one of his results, makes it only 3700 pounds, but this is making six men equivalent to one horse. It is, however, given by Emerson as equivalent to 6300 pounds, that is to raising 30 pounds 210 feet high in a minute, but this is certainly erroneous; much, however, will depend upon the nature of the exertion, and whether the man is accustomed to exert his strength in the manner required.

(5.) It is almost impossible to employ a horse as a first mover without locomotion, that is without causing him to pass over a certain space, and that space we have seen is 20 miles in a day, in order that he may produce the greatest effect; now the mere exertion of passing over this space without any draught is a great deduction from his absolute force: so also in a man, if his effort is such as to require locomotion, all the muscular power employed in the mere translation of his body over this space is lost as to mechanical effect, and accordingly it is found that a man will produce the greatest mechanical result when he is fixed in his place, as at a winch or rowing in a boat; for although in the latter case he is really transferred from place to place, it is at little expense of muscular force. At a winch, the only non-efficient muscular exertion is that of raising the centre of gravity of the body from the lowest stooping position to the upright position. In rowing, it is bringing the body from an inclined position backwards to the same forward, and this being less than the former, the man is found capable of producing more useful effect in this mode of applying his force than in any other. The next best mode of application is at the winch, and the third at the capstan bar, for here, although there must be considerable locomotion, yet the direction of his muscular power is advantageously applied; and where the purchase is great and the duration of the effort small, there is perhaps no other way of employing a man's muscular power to so great advantage.

A method of employing the power of men for involuntary labour has been recently introduced into this Country, called the Tread-wheel, which will be described in a subsequent page amongst the simple Machines; and we shall in this place only observe upon it, that the effort required here, is for the man to be constantly lifting his

Machinery.

Maximum
effect

Men on a
Tread-
wheel.

Manufactures.

own weight; as a medium we may therefore consider him lifting a weight of 140 or 150 pounds, whereas we have seen that the most useful effect is produced when the man is opposed to only about 30 pounds. Consequently, although in this machine there is no lost effort in locomotion, yet the load exceeding that which gives the maximum effect nearly five times, it is a very disadvantageous mode of application, however proper it may be for employing the idle and disorderly. It will be seen under the article Tread-mill that the maximum effort of a man in this mode of application cannot be stated at more than 3750.

Men unloading coals.

(6.) Another way in which the power of men is employed to a considerable amount, is, in unloading the colliers on the river Thames, and a more disadvantageous mode of application can hardly be conceived; none but the strongest and most robust men can undertake it, and while at work the exertion is so great, that they work almost naked, and yet after all the amount of labour in actual numbers is scarcely half the above effect at the Tread-mill.

The way in which this operation is conducted is as follows: a stageing is erected about seven feet above the deck, upon which the coals are first lifted, and thence shot into barges. The number of men employed are

Four men in the hold filling,

Four men for what is called whipping,

One man at the basket.

The quantity of coals brought up each time is $1\frac{1}{4}$ hundred-weight, and the mean depth of the centre of gravity of the coals is about 20 feet below the platform; a pulley is placed in the rigging, over which a rope passes to the hold, and to which the basket, when filled, is attached. The four whippers now run up a sort of step-ladder, 5, 6, or 7 feet, according to circumstances, each having in hand a rope, which unites in the one which is attached to the loaded basket, then each using his greatest effort catches up a certain length of rope, thereby raising the basket a little, and then all jumping down at the same time and using still a considerable further muscular effort when down, the coals are raised to the platform with a sudden jerk.

The quantity these nine men will raise per day, in a general way, varies from 60 to 80 tons; but we are informed they have raised as much as 200 tons; and a gentleman on whom we can rely says he has had 105 chaldrons, or about 126 tons, whipped out in one day, but it was considered a great day's work. Of these nine persons four only are employed in lifting, and reckoning only these four we shall see how very inadequate the result is compared with the labour.

Let the day's work be 20 tons for each of these men, raised 20 feet, this gives $20 \times 20 \times 2240 = 896,000$ pounds raised a foot high in the day, or $\frac{896,000}{8 \times 60} = 1866$

pounds one foot high in a minute, which is not one-third of what has hitherto been considered a man's power, nor half the reduced measure of it we have assumed in the preceding page from the most recent experiments, and only just half the Tread-mill day's work, although this, as we have seen, is itself a disadvantageous mode of application. We are aware that the nature of the work to be performed must, in many cases, determine the mode of application of the power, whether advantageous or not; but we are strongly of opinion there is no occasion in this case, in unloading a vessel of coals, to be confined to this absurd way of what is called whipping.

These are the principal cases in which the muscular

power of man is employed as a first mover, except where the force required is so small as not to require further aid, or where skill as well as power is necessary to the operation. It seems indeed a reasonable inference from all that has now been stated, that man was designed by his Maker for a higher principle of action—for the exercise of skill and for invention; to regulate the action of the lower animals to the purposes of labour, to convert air, fire, and water to his service, and, only where skill and direction are required, to become himself a mechanical agent.

Machinery.

(7.) *Of the Wind as a first mover.*—Of all mechanical agents the Wind is the most uncontrollable, the most uncertain, and its effects the most difficult to estimate, not from any mystery in the nature of its action, but simply from its natural variability. If we could regulate the velocity of the Wind impinging upon a body to be moved by it, there would be no difficulty in reducing its action to a comparison with other forces, but its perpetual changes, not merely in direction but in power, render such a reduction nearly impossible. If the velocity could be determined and remained constant, the pressure of the Wind on any given surface might be easily computed, it being equal to the weight of a column of air of the density of the atmosphere, of such a height that a heavy body falling from that height would acquire the given velocity. Now taking the mean density of the air to that of water as $\frac{1}{800} : 1$, we may easily compute the

Power of the Wind as a first mover.

pressures in pounds avoirdupois, upon a square foot of surface, and hence of course the pressure for any surface. Let v be the velocity in feet per second, then g denoting $16\frac{1}{2}$ feet, the space fallen by a heavy body in a second, we have $v = 2 \sqrt{gs}$ or $s = \frac{v^2}{4g}$ for the height of the column of air, the pressure or weight of which on a square foot will therefore be (taking the cubic foot of water at $62\frac{1}{2}$ pounds) $p = \frac{62\frac{1}{2} v^2}{3200 g}$ pounds. This theo-

retical deduction, however, it appears, does not agree with actual observation, when the velocities are considerable, the cause of which is probably to be found in the elastic nature of the air; and as our inquiries here are rather practical than theoretical, we shall content ourselves with merely stating the actual observed pressures on one square foot of surface at different velocities, as given by Mr. Smeaton, in the *Philosophical Transactions*, vol. li.; see also Hutton's *Abridgement of Phil. Trans.* vol. xi.

Miles per hour.	Feet per Second.	Pressure per square foot, in pounds.
1	1.47	.005
2	2.93	.020
3	4.40	.044
4	5.87	.079
5	7.33	.123
10	14.67	.492
15	22.00	1.107
20	29.34	1.968
25	36.67	3.075
30	44.01	4.429
35	51.34	6.027
40	58.68	7.873
45	66.01	9.963
50	73.35	12.300
60	88.02	17.715
80	117.36	31.490
100	146.70	49.200

Manufac-
tures.
Maximum
effect.

Having thus the perpendicular force of the Wind on a given surface, we have to consider the manner in which it can be applied for mechanical effect; and this is commonly by means of windmill sails, which are placed obliquely to the plane of their motion and to the direction of the Wind, so that, the latter impinging upon them, its force is resolvable into two forces, one according with the direction of the motion of the sails, and the other perpendicular to it: by the former of which rotation and mechanical effect are produced. Here then again arises another question, what ought to be the angle of the sails' obliquity, to produce the best effect? If we had merely to determine the angle at which the sails should be placed to receive the greatest impulse from the Wind at right angles to its direction, the sails being supposed at rest, we should find it to be 45° , but this angle would not give the greatest velocity: to attain this the angle requires to be about 55° ; but neither of these angles will give the greatest mechanical effect. In the windmill, as in all other Machines, a certain velocity opposed to a certain weight is requisite for the maximum effect; and generally speaking, these are far better obtained from actual experiment than from theoretical deductions, however valuable the latter may be in guiding our first experimental researches. On this head we shall offer some remarks in our description of this important engine, our only business in this place has been to give a general illustration of the nature of the Wind as a first mover. The angles of inclination of the sails, their size, form, and general arrangement, will be best treated of in the article referred to.

Water as
a first
mover.

(8.) *Of Water as a first mover.*—Water acts as a first mover either by its weight only, by its momentum only, by its weight and momentum combined, or by its pressure. In the former cases it commonly is made to act on a wheel, and in the latter by its action on a piston.

Balance
wheel.

The nature of its action on different wheels, in these several cases, will be more particularly described under the article Water mill; it will be sufficient here merely to explain the general character of its action. In the former case the circumference of the wheel is supplied with a number of buckets, the shape and number of which will be explained in the article referred to; the Water is received into these buckets above the centre or axle of the wheel, and thus, being heavier on that side, motion will ensue, and as fresh buckets arrive at the proper height to receive the Water, while those below have emptied themselves, a constant tendency to motion is created and rotation is produced. A wheel of this kind is called a *balance wheel*.

Overshot
wheel.

When the Water instead of being received into the bucket on its own level, is allowed to fall from a certain height, being commonly in that case conducted over the top of the wheel, it acts first by its momentum and then by its weight, although the former part of the effect is but small. This wheel, which differs however in no respect in its form from the former, is called, in consequence of the manner in which it receives the water, an *overshot wheel*.

Undershot
wheel.

When the Water acts by its momentum only, the circumference of the wheel, instead of being supplied with buckets, as in the preceding case, is now furnished with floats or float boards, and being exposed to the action of a running stream, generally increased in rapidity by a previously regulated fall, is thus driven round, and its force communicated to any Machinery intended to be worked by it. This is called an *undershot wheel*.

Sometimes instead of the Water having a previous fall and thereby being made to strike the floats at the bottom of the wheel with an increased velocity, the wheel is fixed in what is called a *race*, formed of stone work, agreeing with the curvature of the wheel, and being thus let on from its own level, acts both by its weight and momentum. This is called a *breast wheel*. This wheel differs in its form from the last in this, that it must necessarily be close boarded, or technically close *soled* round its circumference, whereas the other is an open wheel; the sides are also sometimes close *shrouded*, or closed in on the sides to retain the Water, and it thus becomes a sort of bucket wheel, although in consequence of the Water being retained by the sides of the race these buckets are not made of the same shape as the former. In some cases the shrouding is omitted, in which case great accuracy is requisite in forming the race and hanging the wheel.

Machinery
Breast
wheel.

The above are the principal methods in which Water is made to act as a first mover, and our object here is simply to ascertain, as far as we are able, the amount of its action in any given case, in terms of our dynamic unit or horse-power, but unfortunately this is not very easily, or at least not very satisfactorily to be accomplished.

(9.) If the head of Water thrown upon an overshot or balance wheel produced its whole effect, we should be able at once to state the amount of that effect in horse-powers, but unfortunately there is still great uncertainty in the relation between the actual head and discharge of Water, and the mechanical effect it produces in different cases; and the same remark applies also to the undershot wheel, and more strongly still to the breast wheel. From several experiments by Mr. Smeaton, it appears, that in overshot Water wheels the ratio between the power and effect, at its maximum, varies from that of 10 to 7.6, to that of 10 to 5.2, or nearly from 4 to 3, to 4 to 2; the former belonging to those cases where the quantity of Water expended was the least, and the latter to those in which the quantities were greatest; and he therefore assumes 3 to 2 as a medium ratio between the power and effect in overshot wheels, while in undershot wheels the ratio between the power and effect, at a maximum, is as 3 to 1. The ratio therefore of effect in overshot wheels and undershot wheels, both acting to the best advantage and under the same circumstances of quantity and fall, at a medium, is as 2 to 1.

Compara-
tive power
of Water
wheels.

Now these ratios, if they rested upon a tolerable certain basis, would enable us at once to compare the effect of a Water wheel with the unit of mechanical force, and consequently with the power of a horse or steam-engine. We should only have to estimate the quantity and weight of Water fallen in a minute, and the amount of the mean fall in feet; then multiplying the weight in pounds by the number of feet, and dividing the product by 33,000, would give the amount of the motive force in horse-powers, and two-thirds of this, according to the proportions above stated, would be the useful effect in the overshot wheel, and one-third of it in that of the undershot wheel.

Unfortunately, however, the above ratios, which are drawn from experiments on a comparatively small scale, and where every precaution was taken to ensure accuracy, and which still gave only an assumed mean between one half and three-fourths, cannot be applied with any certainty in real practical cases; so that after all, notwithstanding they may assist us in some degree in estimating the effect which may be expected to be obtained from a given head and fall, the subject must always be ap-

**Manufac-
tures.** proached with caution and deliberation, particularly where the work to be performed cannot be effected without a certain amount of power, as in the case of Rolling mills and others of a similar kind.

We have mentioned the case of Water under compression being employed as a motive power; this occurs, however, only in a few instances, and then principally from considerations of convenience, as in the case of Bramah's Planing machine, and a few others; it is therefore not that description of motive power which requires to be considered in this place.

**Steam as a
first mover.** (10.) *Of Steam as a first mover.*—This is a subject on which it will be necessary to enter at considerable length, when we have to treat of the Steam-engine; we shall therefore be in this place as concise as possible, in speaking of its mechanical effects as a first mover, the principles on which the estimation of the power depends, and the usual allowances made for friction, imperfect vacuum, and reduction of temperature; all which subjects must be examined at considerable length in the article referred to. For the present purpose it will be sufficient to state generally, that in a Steam-engine, the power obtained depends upon the difference of pressure of the Steam against the piston on one side, and that of the vapour or imperfect vacuum on the other, and on the area and velocity of the piston, without regard to its length. To estimate the actual power from these data only, however, would not give a measure of the useful effect of an engine, because a part of this power is employed in producing the vacuum, and in overcoming the friction and inertia of the different parts; certain allowances therefore become necessary, which we shall content ourselves with merely stating in this place, reserving the examination of the principles on which they rest, till we have to treat of the engine itself.

Every body knows that the medium pressure of the atmosphere, and of Steam at the boiling heat of water, is about equal to 30 inches of quicksilver, or to 34 feet of water, or to $14\frac{3}{4}$ or 15 pounds on each square inch of surface pressed. If therefore we had a pressure of Steam on one side the piston only, equal to the pressure of the atmosphere, and a perfect vacuum on the other, the power would be equal to 15 times the number of inches in the area of the piston, in pounds avoirdupois; but in the common low-pressure engine the Steam in the boiler is generally kept at a pressure of from $2\frac{1}{2}$ to 4 pounds, exceeding the atmosphere, and instead of a perfect vacuum, on the other side, or in the condenser, the pressure of the vapour, &c. amounts to about 2 pounds; that is in common language it is said to have a minus pressure of about 13 pounds, or equal to a column of mercury of about 26 inches, varying from this to 28 inches, according to the perfection of the workmanship and other causes. Suppose, as an example, that the minus pressure is equal to 26 inches, or 13 pounds, and the pressure of Steam on the piston to be the same as in the boiler, 4 pounds, that is allowing for no loss of temperature in the passage of the Steam, then the actual motive power of the piston would be $4 + 13 = 17$ pounds upon every square inch of its surface. This, however, is not all effective power; a considerable portion of this is absorbed

in working the air-pump to produce this imperfect vacuum Machinery. and in overcoming the friction and inertia of the Machine, the latter being always considerable, in all reciprocating parts, as the pistons, the beam, &c. We cannot of course in this stage of the inquiry enter into an examination of the effect of all these counteracting causes; we shall therefore content ourselves by merely stating at present that about one half of the minus power is consumed in the way we have stated, in the reduction of temperature and the consequent reduction of the elastic power of the Steam in its passage from the boiler to the cylinder, and to the still further reduction in the latter part of the stroke in consequence of the Steam being shut off before the stroke is completed. All these circumstances considered, it is found in practice that the actual effective power of the engine is equal to a pressure estimated by half the minus pressure of the condenser, plus the pressure shown at the boiler, beyond that of the atmosphere; so that in the above case, the actual effective power would be $6\frac{1}{2} + 4 = 10\frac{1}{2}$ pounds, and this multiplied by the area of the piston in inches, and its velocity in feet per minute, and the product divided by 33,000, the quotient will show the number of nominal horse-powers of the engine, each horse-power being, as has been already stated, equivalent to $1\frac{1}{2}$ times the actual medium power of a horse. A more detailed examination of the power of Steam will be found in the Chapter on the STEAM-ENGINE.

What is above advanced is perhaps sufficient for our present object, which has been merely to give a general idea of the comparative power of the principal first movers, by means of one common standard or dynamic unit. It is obvious from all that has been stated that much uncertainty must after all hang upon the comparison. The powers of men and animals differ very greatly, each in its class. The power or rather the velocity of the Wind is exceeding uncertain and variable. Water is also liable to considerable fluctuations in supply, and great impediments interfere in the action of large heavy wheels; and even in the steam-engine its action is not uninfluenced by atmospheric changes, and of course much also of its power depends upon the accuracy of workmanship, the care and diligence of the engineer, and various other circumstances; so that the comparative value we have been enabled to assign to the several first movers under consideration, must be taken as they are given, not as absolute and certain, but as the best medium results that can be obtained, where all the elements on which they are founded are so variable and capricious.

(11.) It may not be uninteresting to the reader, in concluding these few remarks on the relative power of men, horses, windmills, water mills, and steam-engines, to give the following Tabulated results, collected with great care by Dr. Young, and published in his Lectures on Natural Philosophy; remarking only that on a full comparison they will be found to differ considerably from each other, and we trust will justify what has been repeatedly stated in the preceding pages, relatively to the uncertain data on which all comparisons of this kind must rest.

**Tabulated
results of
various ex-
periments.**

Manufactures.

TABLE I.—Showing the immediate Force of Men without Deduction for Friction.

Machinery.

	Force or Men's Power.	Duration. h. m. s.	Day's Work.
A man weighing 133 pounds Fr. ascended 62 feet Fr. by steps, in 34", but was completely exhausted. Amontons.....	.38	0 0 34	
A sawyer made 200 strokes of 18 inches Fr. each, in 145", with a force of 25 pounds Fr. He could not have gone on above 3 minutes. Amontons.....	.82	0 2 25	
A man can raise 6 pounds Fr. 1 foot Fr. in 1" for 8 hours a day. Bernoulli.....	.94	8 0 0	.75
A man of ordinary strength can turn a winch with a force of 30 pounds, and with a velocity of 3½ feet in 1", for 10 hours a day. Desaguliers.....	1.43	10 0 0	1.43
Two men working at a windlass, with handles at right angles, can raise 70 pounds more easily than one can raise 30. Desaguliers.....	1.66	....	1.66
A man can exert a force of 40 pounds for a whole day, with the assistance of a fly, "when the motion is pretty quick, as above 4 or 5 feet in a second." Desaguliers, Lect. 4. But from the annotation it appears to be doubtful whether the force is 40 pounds or 20.....	2.7	....	2.7
For a short time a man may exert a force of 80 pounds, with a fly, "when the motion is pretty quick." Desaguliers.....	4.9	0 1 0	
A man going up stairs ascends 14 metres in 1". Coulomb.....	1.6	0 1 0	
A man going up stairs for a day raises 250 chilogrammes to the height of a kilometre. Coulomb....	....	....	.653
With a spade a man does ½ as much as in ascending stairs. Coulomb.....	....	....	.533
With a winch a man does ⅓ as much as in ascending stairs. Coulomb.....	....	....	.345
A man carrying wood up stairs raises, together with his own weight, 100 chilogrammes to 1 kilometre. Coulomb.....	....	....	.299
A man weighing 150 pounds Fr. can ascend up stairs 3 feet Fr. in a second, for 15" or 20". Coulomb.	7.01	0 0 20	
For half an hour 100 pounds Fr. may be raised 1 foot Fr. in a second. Coulomb.....	1.52	0 30 0	
According to Mr. Buchanan's comparison, the force exerted in turning a winch being made equal to the unit, the force in pumping will be.....	.61		
In ringing.....	1.36		
In rowing.....	1.43		

According to Schulze's experiments, the force which a man or a horse can exert with the velocity v , is $= f \left(1 - \frac{v}{a}\right)^2$ f being the force in equilibrium, and a the velocity without resistance. This is a formula of Euler.

Another of his expressions, $f \left(1 - \frac{v}{a}\right)$, does not agree so well with Schulze's experiments, but Euler's theory is founded on assumptions wholly arbitrary. According to the first formula, the greatest mechanical effect would be when $v = \frac{1}{2} a$; according to the second, when $v = \sqrt{\frac{1}{3} a}$.

Allowing the accuracy of Euler's formula, confirmed by Schulze, supposing a man's action to be a maximum, when he walks $2\frac{1}{2}$ miles an hour, we have $7\frac{1}{2}$ for his greatest velocity, $.04 (7\frac{1}{2} - v)^2$ for the force exerted with any other velocity, and $.016 v (7\frac{1}{2} - v)^2$ for the action in

each case; thus,

When the velocity is one mile an hour, the action is ..	.929
When two miles.....	1.31
Three.....	1.33
Four.....	1.07
And when five.....	.682

And the force in a state of rest, $2\frac{1}{2}$ or about 70 pounds, with a velocity of two miles 36 pounds, with three 24 pounds, with four 15. It is obvious that in the extreme cases this formula is inaccurate, but for moderate velocities it is probably a tolerable approximation. Porters carry from 200 to 300 pounds at the rate of three miles an hour; chairmen walk four miles an hour with a load of 150 pounds each; and it is said that in Turkey there are porters who, by stooping forward, carry from 700 to 900 pounds, placed very low on their backs. The most advantageous weight for a man of common strength to carry horizontally is 111 pounds, or if he returns unladen, 135. With wheel-barrows men will do half as much work as with hods. Coulomb.

Performances of Men by Machines.		Force.	Duration. h. m. s.	Day's Work.
A man raised by a rope and pulley, 25 pounds Fr. 220 feet Fr. in 145". Amontons.....		.594	0 2 25	
A man can raise by a good common pump a hogshead of water, 10 feet high, in a minute, for a whole day. Desaguliers.....		.119	....	.119
By the mercurial pump, or another good pump, a man may raise a hogshead 18 or 20 feet in a minute, for 1 or 2 minutes.....		2.19	0 2 0	
In a pile engine, 55½ pounds Fr. were raised 1 foot Fr. in 1" for 5 hours a day, by a rope drawn horizontally. Coulomb.....		.872	5 0 0	.436
Robinson says that a feeble old man raises 7 cubic feet of water 11½ feet in 1" for 8 or 10 hours a day, by walking backwards and forwards on a lever. Enc. Brit.....		1.13	9 0 0	1.03
A young man weighing 135 pounds, and carrying 30, raises 9½ cubic feet of water 11½ feet high for 10 hours a day, without fatigue. Robinson.....		1.42	10 0 0	1.42
Whinne's machine enables a man to raise a hogshead 20 feet in a minute. Y.....		2.39	0 1 0	
A man unloading coals (art. 6.).....		.852	....	.852
A man at the tread-mill (art. 5.).....		.426	....	.426
Force of Horses.				
Two horses attached to a plough, in moderate ground, exerted each a force of 150 pounds Fr. Amontons.				
We may suppose that they went a little more than 2 miles an hour for 8 hours.....		.736	8 0 0	.591
A horse can draw with a force of 200 pounds 2 miles an hour for 8 hours in the day.....		1.0	8 0 0	.8
With a force of 240 only 6 hours. Desaguliers.....		1.2	6 0 0	.72
The mean draught of 4 horses was 36 myriogrammes each, or 794 pounds. Regnier. This must have been momentary. Supposing the velocity 2 feet in a second, the action would have been.....		21.6	0 0 1	
By means of pumps a horse can raise 250 hogsheads of water 10 feet high in an hour. Smeaton's Reports.....		4.96	1 0 0	

Manufactures.

A horse can in general draw no more up a steep hill than three men can carry, that is from 450 to 750 pounds, but a strong horse can draw 2000 pounds, in a cart, up a steep hill which is but short. Desaguliers.

The diameter of a walk for a horse mill ought to be at least 25 to 30 feet. Desaguliers.

Some horses have carried 650 or 700 pounds seven or eight miles without resting, as their ordinary work; and a horse at Stourbridge carried 11 hundred weight of iron, or 1232 pounds, for eight miles. Desaguliers.

A windmill with four sails, measuring 66 feet Fr. from one extremity to that of the opposite side, and 6 feet wide, or a little more, was capable of raising 1000 pounds Fr. 218 feet in a minute, and of working, on an average, eight hours in a day. This is equivalent to the work of 51 men, as it has been above estimated; 25 square feet of canvass performing about the daily work of a man.

Smeaton says that he has experimentally found a 30 feet sail equal to four horses, or one sail equal to one horse or five men, which, taking the breadth at 4 feet, nearly agrees with the above.

On the Advantages and Disadvantages of different First Movers.

Economy in the selection of first movers.

(12.) In the Introductory Chapter to this Treatise, economy in the subdivision of labour has been considered, and the advantages attending its adoption have been explained at considerable length; but those remarks have in general reference to the employment of labourers, whether men, women, or children, and the basis of it depends upon the dexterity which a person will acquire, and the conveniences which may be rendered him, while he is kept engaged in one particular mechanical process which requires skill rather than strength. Our present object is to inquire into the expense and economy resulting from the nature of the first movers, in which power and not skill is the object to be attained. If we look merely to the pecuniary charge of different first movers, this question would require but little investigation; but there are other considerations, and some of them perhaps scarcely appertaining to our present inquiry, which render the subject in some cases very difficult and perplexing.

We have seen that a horse will perform as much labour, where no skill is required, as five men, and that what is called a horse's power in a steam-engine, is, at the lowest estimate, equal to $1\frac{1}{2}$ times the actual power of a horse, and consequently to $7\frac{1}{2}$ men. We may also state, that, at a medium, 10 pounds of coals in a steam-engine will supply the requisite fuel to produce a horse-power per hour, or about 80 pounds per horse-power for a day, working only 8 hours.

Now the value of 80 pounds, or about a bushel of coals, we can scarcely estimate at more than 1s., the expense of $1\frac{1}{2}$ horse-keep will be perhaps, at a medium, about 3s. 6d., while the expense of $7\frac{1}{2}$ men, at the medium rate of wages for good English labourers, will be 21s. Here then, looking only to the motive power, the relative expense in these three cases, will be about as the numbers 3, 7, and 30. This, however, is not a fair view of the subject, because in the latter case the whole expense is included, whereas in the horse we must consider the first purchase, the expense of harness, stabling, shoeing, grooming, &c.; this perhaps may raise the daily expense of the horse to 4s. 6d.; and in the steam-power we have also, besides the expense of fuel, to include that of oil, tallow, the engineer, stoker, the

first purchase, erection of building; and this will probably, in a medium-sized engine, amount to another shilling per day, and our relative expenses will then be steam power 3s. per day, horse power 6s. 9d., labour power 15s. per day.

Machinery.

The expense of the other sources of mechanical agency cannot be so well estimated; the motive power in a windmill of course costs nothing, and in a water mill it is uncertain, being a hire at a greater or less charge, according to circumstances; both these Machines, however, are worked at considerably less expense than the steam-engine; but the one is uncertain and scarcely available to any process where steady and constant results are required, and the other, although subject to less uncertainty, is only a local power, and cannot be, like the steam-engine, made available in all situations. The question of economy and expense, therefore, rests between the man, the horse, and the steam-engine; and here, it must first be taken for granted, when we make a comparison of this kind, that there is sufficient employment for the steam-engine; for if this is not the case, the expense, as compared with the value of its production, is much increased; its power will be also deteriorated, for want of being kept regularly at work; and its wear and tear, while it is at work, will be considerably increased, and its final duration much shortened. We have lately seen one of the earliest of Bolton and Watt's engines, which has been in constant use above forty years, performing admirably; it has of course undergone certain repairs, and certain parts have been replaced by new work; but had this engine worked only a day or two in a week, or for a week or two in a month, it is not unlikely that it would long before this have been entirely worn out and rejected. There are, it is true, some cases where great power is required, although not wanted to be in constant application, that is where only an engine of a large kind is competent to produce the desired effect. In such cases, notwithstanding the above consideration, a powerful engine must be procured; but these instances lead merely to considerations of expediency and necessity, and form no part of the question of economy, as regards the application of other first movers.

The point to which we are desirous of directing attention, is where the demand is such as to give due employment, and where the inquiry is merely whether it will be best to employ horse or steam-power, or horse or man-labour; for there is seldom a question between the employment of the power of man or steam, although there are some such, as in cotton-spinning-engines, power-loom weaving, &c.

Where the question is between horse and steam-power, we have already seen the great advantage, in point of expense; but this is not all the advantage, nor all that enters into the question of what is to be understood by the term economy. We have to look to the convenience of application, the steadiness and uniformity of power and motion, and if it did not rather belong to a different inquiry, we might point out its bearing upon the national advantages and resources. There is no doubt horses, like all other objects of sale, are supplied in the market, we may say produced, in proportion to the demand; every new application of steam therefore to effect what had hitherto been effected by horses, either serves to diminish the value of horse-labour, or the number of horses in the Country.

On the former supposition, other articles produced by horse-labour are reduced in price, and conveniences

Manufac-
tures.

depending on horses are obtained at a cheaper rate ; or on the other hand, so many less horses are to be maintained, and the land which supplied their food is now available to the support of man ; besides which, the demand for human labour is increased. Miners must be employed to extract the coal ; ships built and sailors to transport them ; artificers to erect the necessary buildings, and engineers are wanted in greater numbers to form steam-engines than horse-mills ; and after all, the article produced may be purchased by the general consumer at much less price. We must conclude, therefore, that where the demand is sufficient, steam-power is in every respect preferable to horse-labour.

The question is not quite so simple in comparing horse with man-labour. As far as regards the expense, indeed, we have already seen that it is at least two to one in favour of horse-power ; but what were in the former comparison advantages, in a national point of view, are the contrary in this. If the substitution of steam-power for horse-power have a tendency to diminish the number of horses, and thereby to reduce the price of human food, it follows that the substitution of horse-labour for man-labour tends to increase the number of horses, and to increase the price of human food. However little doubt there may be therefore in considering merely the first expense to individuals, the substitution is very questionable when looked at under a more comprehensive point of view ; and this is more particularly the case, if, while the horses are made to work, men are obliged in consequence to remain idle, which it is to be feared is too often the case, in our agricultural districts, where the thrashing machine supplies the place of the flail, which is an operation requiring some skill as well as strength, and therefore not degrading to a man, as it would be to make him the immediate motive agent in the thrashing machine itself.

The same objection does not apply to the substitution of steam-power for man-labour in our manufacturing districts, but quite the contrary ; for in the first place this abstracts no land from the production of human food ; and although every such new substitution must throw some hands out of employ, the general demand is so much increased by the cheapness of the production, that these again are soon called into action ; every body is more cheaply clothed ; and the general exportation of the article being increased, calls for additional labour, and thus contributes to the riches and resources of the Country.

As a proof of the extraordinary advantages of this substitution, we may mention the following fact : that in 1767 the number of hands engaged in our Cotton manufactories did not amount to 30,000, the article was dear, and few the number that could indulge in its use, either for dress or household purposes ; at this time, in consequence of the skill which has been bestowed in the substitution of Machinery for manual operations, instead of employing 30,000, we have employment for upwards of a million, and the article being furnished to the consumer at less than a quarter of its former price, it is now in general use with all, even the lowest classes of society. But we shall never be able to trace such results to the substitution of horse for man-labour.

To pursue the question beyond this point, would be to enter into a discussion on Political Economy, which is not within our province. Our only object has been to compare mechanical expenses and economy, and if we have deviated a little from this line of argument, it has not been

a matter of choice but of necessity, in consequence of Machinery the intimate connection of the two subjects.

II. OF RETARDING FORCES.

(13.) If Machines could be made perfect, the effect produced by any combination of mechanical powers would lead to results precisely equivalent in measure to the forces by which motion is produced ; but in no Machine can this be expected, in consequence of the retardation to which all are necessarily liable ; such as friction, rigidity of cords, ropes or bands, the resistance of the air, &c. Of these counteracting forces, however, it will perhaps be sufficient merely to examine the amount of the two former ; for although the resistance of the air is sometimes considerable, and is even in a few cases designedly introduced to regulate the motion of a Machine, yet generally it is not considerable, and its retardation may therefore be neglected, except in those cases to which we have alluded, and which will be treated of more appropriately in another article than in this place.

On friction.—In the article STATICS, in our Treatise on Amount of Theoretical Mechanics, we have investigated the theory of friction. friction, as far as its influence affected the sensibility of the equilibrium of bodies ; but we have reserved its dynamic effect, or its influence on the motion and force of moving bodies, for the present article ; although by mistake in the article in question its place is referred to the general alphabetic arrangement. In all investigations relative to the dynamic effect of moving bodies, we are under the necessity, in theory, of considering the surfaces of bodies as perfectly smooth, and that they slide over each other without resistance. But this is far from being the practical state of things : there are no bodies perfectly smooth, nor any Machine that is not more or less impeded in its motion by friction, or the rubbing of its parts, whether it be the teeth of wheels against each other, pivots and gudgeons against their bearings, or in fact any one surface pressing and rubbing on another ; indeed in many Machines, such as Polishing mills, Grinding mills, Boring and Sawing mills, &c. the entire effort is to overcome friction or something very much resembling it ; so that a knowledge of its nature and effects seems absolutely necessary to enable us to apply the principles of theoretical mechanics to useful practical purposes.

Much attention has been accordingly paid to this subject, by many distinguished philosophers and practical engineers, but by far the most extensive series of experiments and the most valuable deductions are those which we owe to George Rennie, Esq. F.R.S. published in the *Philosophical Transactions* for 1829, from which we shall take the liberty of extracting and abbreviating those parts which belong more immediately to our present inquiry. The author introduces his experiments by a short sketch of previous attempts. The nature of friction, he observes, has excited the attention of most of the writers on practical Machinery from the period of the first two Dissertations of Amontons, in the year 1699, down to the more elaborate researches of Coulomb and Vince, in 1799 and 1784. Amontons affirmed that friction was not augmented by an increase of surface, but only by an increase of pressure ; and from subsequent experiments drew a conclusion that friction amounted to one-third of the pressure, and the amount was the same both with wood and metals when unguents were interposed. He likewise concluded that friction increased or diminished with the velocity and varied in the ratio of the weight and pressure of the rubbing parts, and the time and

Manufactures. Different writers on friction. velocity of their motions. These hypotheses were adopted, more or less, by most of the Philosophers after Amontons, but particularly by De la Hire, who satisfied himself by several experiments of the truth of Amontons' conclusions, but they were questioned by Lambert, although without the test of experiments. Parent suggested an investigation of these subjects in his proposition of the spheres, by determining the angle of equilibrium at which a body, resting on an inclined plane, commenced sliding; and the celebrated Euler, in a very elaborate paper, conceived it to depend upon the greater or less approximation of the asperities of the surface, brought into contact by pressure, the resistance to which, in agreement with Amontons, he allows to be one-third of the pressure. Of the effect of velocities he was however uncertain; but observed that when a body begins to descend an inclined plane, the friction of the body will be to its weight or pressure as the sine of the plane's elevation to its cosine, &c. But when the body is in motion, the friction is diminished one half. Muschenbroek and others maintained that friction increased with the surface; and Bossut distinguished it into two kinds; the first being generated by the gliding, and the second by the rolling of the surface of a body over another; and remarked, that it was affected by time, but that it followed neither the ratio of the pressure nor of the mass. Brisson attempted to construct a Table of coefficients, to denote the value of the friction of different substances; but they are inapplicable to practical purposes, for want of proper experiments. Desaguliers considered the nature of friction with a good deal of attention, but principally with reference to the rigidity of cords. He, however, quotes the experiments of Camus, as best calculated to illustrate the subject; nevertheless, they were made on too small a scale to derive any satisfactory conclusions. Schober and Meister coincided with Muschenbroek in the opinion, that the spaces were as the squares of the times, in the case of a body uniformly accelerated. The opinions of many other eminent Philosophers, such as Leibnitz, Varignon, Leupold, Bulfinger, Daniel Bernoulli, Ferguson, Rondelet, Gregory, Leslie, Young, Olivier, &c. might be quoted. But it is to Coulomb, principally, that we are indebted for the knowledge we possess of this kind of resistance.

Coulomb. (14.) In the year 1779 the Academy of Sciences, at Paris, being desirous of rendering the laws of friction, and the effects resulting from the rigidity of cords, applicable to Machines, Coulomb undertook, in the Arsenal at Rochfort, a very extensive series of experiments, which he afterwards published in 1781, under the title of *Théorie des Machines simples, en ayant égard au Frottement de leurs Parties, et à la Roideur des Cordages*. This Memoir is divided into two parts. The first treats of the friction of surfaces gliding over each other, and the second enters into an examination of the rigidity of cords, and the friction of the rotary movements of axles. Coulomb commences his Work by examining the friction of plane surfaces gliding over each other, distinguishing it into two kinds; the first resulting from time, and the second from velocity. The first may depend on four different causes; viz.

- 1st. The nature of the bodies in contact.
- 2d. The extent of surface.
- 3d. The pressure on the surface.
- 4th. The time the surfaces have been in contact; and he even adds a

VOL. VII.

5th. The state of the atmosphere; which he however Machinery. thinks may have little influence.

The case of bodies gliding over each other with a certain velocity, he considered to be referable to the first three causes, besides the velocity of the planes in contact.

With regard to the physical causes of friction, he coincides with the opinions of Amontons and others, that it arises from the entangling of the asperities, which can only be disengaged by bending or breaking. These experiments led to some important results; viz.

1st. That the friction of wood on wood without unguents, was in proportion to the pressure, which attained its maximum in a few minutes after repose.

2d. That the effects of velocities were similar; but the intensities were much less to keep the body in motion, than to detach it from a state of rest, oftentimes in the ratio of 22:95.

3d. That in the case of metals, the results were likewise similar, but the intensity was the same, whether to disturb or maintain the motion of the body.

4th. That with heterogeneous surfaces, such as those of wood and metals gliding over each other, the intensity did not attain its limit sometimes for days.

In general, however, with woods and metals without unguents, velocities were found to have very little influence in augmenting friction, except under peculiar circumstances.

The Treatise of Coulomb is illustrated by a great variety of interesting experiments, and forms the most valuable Work we possess on the subject.

(15.) In the year 1784, Dr. Vince endeavoured by Vince some very ingenious experiments to determine the laws of retardation, together with the quantity and the effect of surface on friction. The results were, that the friction of hard bodies, in motion, was a uniformly retarding force, but not so with cloth and woollen, which were found, in all cases, to produce an increase of retardation, with an increased of velocity.

That the quantity of friction amounted to about one-fourth of the pressure, and that it increased in a less ratio than the quantity of matter or weight of the body.

That when the surfaces varied from 1.61:1 to 10.06:1, the smallest surface gave the least friction: and finally, that friction was greatly influenced by cohesion.

Dr. Vince's conclusions regarding the laws of retardation, were partly confirmed by the late ingenious Mr. Southern of Soho, who in a Letter to Dr. Vince, in 1801, communicated the results of several experiments on the surfaces of the spindles of grindstones, moving with great velocities; when it was found, that with the rubbing surfaces, moving at the rate of 4 feet per second over a length of surface of 1000 feet, the resistance, arising from the friction of 3700 pounds of matter, only amounted to one-fortieth of the weight.

(16.) Mr. Rennie having given the above interesting Rennie's detail of previous experiments, proceeds to describe those experiments. made by himself; the scale of which far exceeded any previously undertaken, the pressures employed in many cases amounting to several hundred weight. The apparatus consisted of a plane horizontal bed, but which might be elevated to any proposed angle; and the measure of the friction was accordingly obtained in two ways; first by determining the weight on a scale requisite to draw a given load along the horizontal plane, and secondly, by elevating the plane till the angle was such as to cause the effect of Gravity to just overcome the friction. In the latter case, we know that when a

Manufactures.

body is just sustained on an inclined plane, the weight of the body, the pressure on the plane and its force parallel to the plane vary as the radius, the cosine, and sine of the plane's elevation, and therefore the weight being w , the amount of the friction will be

$$\sin a \cdot w = \frac{w}{\operatorname{cosec} a}. \quad \text{Whence, the angle being given,}$$

the cosecant of that angle will express the fraction of the weight which is equivalent to the friction.

Friction of wood on wood.

This being premised, and passing over the first experiments of cloth on cloth which are not immediately applicable to our present inquiry, we come to those of wood on wood, from which the following abstract has been made, and will be found very valuable. The plane was here placed horizontally, and the rubbing surface measured two square inches. The mean stated in the Table is obtained by taking the general mean of all the results drawn from experiments on weights, varying from half a hundred weight to ten hundred weight, thirteen hundred weight, &c. And in order to show the greatest variability in the law obtained, we have stated the two extreme results in two separate columns with the weights with which they occurred.

TABLE I.—Of the Friction of Wood on Wood.

In these experiments a descending weight was made to draw another along a horizontal bed or plane.

Nature of the rubbing surface.	Mean of weight to friction.	Number of experiments from which the mean is taken.	Weights moved.	Weights which gave the least ratio.	Weights which gave the greatest ratio.
Red teak on red teak	8.82 to 1	13	from 1 cwt. to 13 cwt.	cwt. 1	prop. 9.90
American live oak on American live oak	7.65 to 1	12	from 1 cwt. to 12 cwt.	cwt. 8	prop. 9.15
Pine on pine	3.40 to 1	4	from 1 cwt. to 3 cwt.	cwt. 3	prop. 4.01
Black beech on black beech	7.13 to 1	11	from 1 cwt. to 10 cwt.	cwt. 4	prop. 8.00
Norway oak on Norway oak	7.67 to 1	9	from 1 cwt. to 8 cwt.	cwt. 8	prop. 8.53
English oak on English oak	7.83 to 1	6	from 1 cwt. to 5 cwt.	cwt. 1	prop. 8.14
Hornbeam on hornbeam	6.57 to 1	8	from 1 cwt. to 7 cwt.	cwt. 7	prop. 7.38
Elm on elm	5.86 to 1	9	from 1 cwt. to 8 cwt.	cwt. 1	prop. 6.38
Honduras mahogany on Honduras mahogany	5.96 to 1	12	from 1 cwt. to 11 cwt.	cwt. 1	prop. 6.76
Yellow deal on yellow deal	2.88 to 1	6	from 1 cwt. to 5 cwt.	cwt. 5	prop. 3.03
White deal on white deal	3.81 to 1	3	from 1 cwt. to 2 cwt.	cwt. 2	prop. 4.94

The results as above given having been obtained by Machinery. a descending weight drawing another along a horizontal plane they were afterwards repeated, or extended, by determining the least angle at which the weight on the inclined plane began to slide. These are given in the following Table, the proportions being obtained from the formula already given; viz. $f = \frac{w}{\operatorname{cosec}}$.

TABLE II.—Of Friction of Wood on Wood.

In determining which, the bed on which the weights rested was inclined till the body slid.

Nature of the rubbing surface.	Weight on the surface.	Angle at which it moved.	Time in descending 11 inches.	Proportion.	Mean Proportion.
Red teak on red teak	10	8° 00	18	7.116	7.617
	20	7.45	15	7.348	
	28	7.15	20	7.861	
	56	7.00	16	8.144	
American live oak on red teak	10	9.00	22	6.314	6.867
	20	8.00	24	7.116	
	28	8.30	20	6.691	
	56	7.45	25	7.348	
Black beech on black beech	10	8.15	20	6.897	7.663
	20	7.20	17	7.770	
	28	7.40	19	7.429	
	56	6.40	21	8.556	
Norway oak on Norway oak	10	8.00	19	7.116	7.966
	20	7.30	20	7.596	
	28	7.00	20	8.144	
	56	6.20	25	9.010	
English oak on English oak	10	9.30	17	5.976	6.923
	20	8.30	17	6.691	
	28	7.40	18	7.429	
	56	7.30	20	7.596	
Elm on elm	10	11.40	19	4.843	5.471
	20	10.30	18	5.396	
	28	10.00	19	5.671	
	56	9.30	19	5.976	
Hornbeam on hornbeam	10	10.00	20	5.671	6.349
	20	9.15	21	6.140	
	28	8.30	20	6.691	
	56	8.15	19	6.897	
Honduras mahogany on hornbeam	10	12.00	22	4.705	4.753
	20	12.30	21	4.511	
	28	11.45	21	4.808	
	56	11.20	23	4.990	
Yellow deal on yellow deal	10	15.00	10	4.732	3.501
	20	17.00	9	3.271	
White deal on white deal	10	18.00	10	3.078	3.794
	20	12.30	11	4.511	
Pine on pine	10	16.00	14	3.488	3.379
	20	17.00	11	3.271	

In reference to the two preceding Tables of experiments Mr. Rennie remarks, "that there is a great deal of irregularity in the results; increase of pressure scarcely increasing the resistance. This may arise in some measure from the surfaces becoming condensed, and thus rendered less liable to abrasion. In some of the cases abrasion had already commenced, but it was not convenient to pursue the experiment further. The soft woods present more resistance than the hard woods, yellow deal on yellow deal being the greatest, and red teak on red teak the least.

(17.) According to Mr. Knowles of the Navy Office, the weight of the Prince Regent of 120 guns on the slips previous to launching was 2400 tons, which divided by the area of the sliding surface of her bilge-ways, (equal to 149,184 square inches,) gives a pressure of 36 pounds per square inch. But the weight

of the Salisbury, of 58 guns, on the slips, according to the area of her bilge-ways, was 44 pounds per square inch. Now by the foregoing Table, the average force required to put in motion the three different kinds of oak under a pressure of 56 pounds per inch is about one-eighth of the pressure, which proportion prevails as high as six hundred weight per inch area; and by Table VI. we find that soft soap, (the ingredient mostly used for diminishing the friction of bilge-ways,) under a pressure of 56 pounds per inch, gives about one-twenty-sixth of the pressure for the friction. Hence the angle at which a building slip should be laid can be easily determined. Coulomb even makes 49 pounds per square inch, and one twenty-seventh for the pressure for hog's lard

The weight of the middle arch (of 151 feet 9 inches span) of the New London Bridge, together with the

centres, was 4900 tons. This acting upon the surface of the striking wedges equal to 540 square feet gives a pressure of 140 pounds per square inch. The angles of inclination of the wedges were equal to $8^{\circ} 45'$, and their surfaces were covered with sheets of copper well coated with tallow. On removing the check pieces, the wedges commenced sliding back slowly and uniformly by the gravity of the arch and centres, and the motion was checked and continued until the arch was left in equilibrio.

(18.) The following experiments were made on different metals sliding on each other, and in order to determine the effect of surface, the same piece of metal was placed in one case flatwise, presenting a surface of 44 inches, and in the other edgewise, having only a surface of $6\frac{1}{4}$ inches.

TABLE III.—Of the Friction of Metals on Metals, as depending on surface, the bodies being moved over a horizontal bed by a descending weight.

Cast Iron on Cast Iron.							Hard Brass on Cast Iron.						
Laid flat, having an area of surface of 44 inches.				Laid edgewise, having an area of surface of $6\frac{1}{4}$ inches.			Laid flat, having an area of surface of 48 inches.				Laid edgewise, having an area of surface of $7\frac{1}{4}$ inches.		
Weight to be moved.	Weight required to move it.	Proportion.	Weight to one inch of area.	Weight required to move it.	Proportion.	Weight to one inch of area.	Weight to be moved.	Weight required to move it.	Proportion.	Weight to one inch of area.	Weight required to move it.	Proportion.	Weight to one inch of area.
lbs.	lbs. oz.		lbs. oz.	lbs. oz.		lbs. oz.	lbs.	lbs. oz.		lbs. oz.	lbs. oz.		lbs. oz.
14	2 2	6.58	0 5.09	2 4	6.20	2 1.1	14	1 14	7.4	0 4 $\frac{3}{4}$	1 11	8.3	1 12
24	3 3	7.53	0 8.72	3 11	6.50	3 8.8	24	3 5	7.2	0 8	4 0	6.0	3 1
36	4 14	7.38	0 13.10	5 14	6.12	5 5.3	36	4 9	7.8	0 12	6 0	6.0	4 10
48	6 8	7.38	1 1.40	7 10	6.30	7 1.7	48	6 4	7.6	1 0	7 13	6.1	6 3
60	8 4	7.27	1 5.80	9 8	6.30	8 14.2	60	7 12	7.7	1 4	9 0	6.6	7 11
72	10 0	7.20	1 10.20	11 7	6.29	10 10.6	72	9 12	7.3	1 8	11 0	6.5	9 4
84	11 10	7.23	1 14.50	13 5	6.31	12 7.1	84	11 8	7.3	1 12	13 2	6.4	10 13
96	13 12	6.98	2 2.90	15 5	6.27	14 3.5	96	13 1	7.3	2 0	14 8	6.6	12 6

Yellow Brass on Cast Iron.							Tin on Cast Iron.						
Laid flat, having an area of surface of 44 inches.				Laid edgewise, having an area of surface of $6\frac{1}{4}$ inches.			Laid flat, having an area of surface of 44 inches.				Laid edgewise, having an area of surface of $6\frac{1}{4}$ inches.		
lbs.	lbs. oz.		lbs. oz.	lbs. oz.		lbs. oz.	lbs.	lbs. oz.		lbs. oz.	bs. oz.		lbs. oz.
14	1 15	7.22	0 5.09	2 1	6.79	2 1.1	14	2 8	5.60	0 5.1	2 12	5.09	2 1.1
24	3 7	6.98	0 8.72	3 8	6.85	3 8.8	24	4 7	5.40	0 8.7	4 8	5.33	3 8.8
36	5 6	6.70	0 13.10	5 1	7.11	5 5.3	36	6 0	6.00	0 13.1	6 7	5.59	5 5.3
48	7 3	6.67	1 1.40	6 10	7.24	7 1.7	48	8 7	5.68	1 1.4	8 14	5.40	7 1.7
60	9 3	6.53	1 5.80	9 3	6.53	8 14.2	60	9 13	6.11	1 5.8	9 13	6.11	8 14.2
72	11 5	6.36	1 10.20	10 5	6.98	10 10.6	72	12 5	5.84	1 10.2	11 13	6.09	10 10.6
84	13 5	6.30	1 14.50	13 12	6.10	12 7.1	84	14 5	5.86	1 14.5	14 5	5.86	12 7.1
96	15 13	6.07	2 2.90	15 1	6.37	14 3.5	96	16 4	5.90	2 2.9	16 4	5.09	14 3.5

From the foregoing experiments it appears that the friction of

Cast iron upon cast iron laid flat, varies from	6.58	to	7.53
Cast iron upon cast iron laid edgewise.....	6.2		6.5
Hard brass upon cast iron laid flat	7.2		7.8
Hard brass upon cast iron laid edgewise	6.0		8.0
Yellow brass upon cast iron laid flat.....	6.09		7.22
Yellow brass upon cast iron laid edgewise ..	6.1		7.24
Tin upon cast iron laid flat.....	5.4		6.11
Tin upon cast iron laid edgewise.....	5.09		6.11

That the friction is nearly the same with cast iron and brass, whether the load be applied on the broad side or on the narrow side of the plates, although the areas of the surfaces are to each other as 6.22 to 1.

That tin being a softer metal and more easily abraded,

the friction increases when a load is applied above 8 pounds per square inch, but remains nearly the same with the broad side as with a narrow side. Generally speaking, the friction is less with the broad side than with the narrow side.

(19.) In the following experiments the object was to extend the preceding results to various metals, but without varying the surface. We have only attempted to give the extreme and mean results, but the entire Table may be advantageously consulted by the practical Engineer, as well as by the Philosophical inquirer. The weights moved, together with their load, varied generally from 14 pounds to 192 pounds. We have taken only those weights in which the proportions differed most from each other, and in a separate Table the several mean results.

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metals.

TABLE IV.—Of the Friction of Metals continued, the bodies being moved on a horizontal plane by a descending Machinery.

Nature of the bodies	Area of rubbing surface.	Weights moved giving the greatest and least ratio.	Weights required to move the preceding.	Greatest and least proportion.	Weight to 1 inch area.
	Inches.	lbs.	lbs. oz.		lbs. oz.
Brass on wrought iron	5.906	24 84	3 11 10 10	6.50 7.90	4 1 14 3.5
Cast iron on cast iron	6.75	24 36	3 0 5 14	8.00 6.12	3 8.9 5 5.3
Soft steel on wrought iron	5.90	84 192	17 5 32 8	4.85 5.90	14 3.5 32 8.0
Brass on steel	5.90	60 36	9 11 5 0	6.19 7.20	10 2.7 6 1.6
Brass on brass	5.90	192 24	44 8 3 8	4.31 6.85	32 8.0 4 1.0
Cast iron on wrought iron	5.90	96 72	17 0 17 5	5.64 6.36	16 4.3 12 3.2
Cast iron on soft steel	5.90	192 48	32 0 7 2	6.00 6.73	32 8.0 8 2.1
Tin on tin	5.90	96 14	36 0 3 10	2.66 3.86	16 4.3 2 5.9
Soft steel on soft steel	5.90	192 48	31 8 6 13	6.09 7.04	32 8.0 8 2.1
Cast iron on hard brass	7.75	36 14	6 0 1 11	6.00 8.29	4 10.3 1 12.9
Wrought iron on wrought iron ..	5.90	24 192	3 13 27 0	6.29 7.11	4 1.0 32 8.0
Brass on cast iron	6.75	84 48	13 12 6 10	6.10 7.24	12 7.1 7 1.7
Tin on wrought iron	5.90	14 48	2 10 7 14	5.33 6.09	2 5.9 8 2.1
Tin on cast iron	6.75	14 60	2 12 9 13	5.09 6.11	2 1.2 8 14.2

TABLE V.—Of the Mean Results of the Friction of Metal on Metal, deduced from the general Table.

Nature of bodies.	Area of rubbing surface.	Mean of the weights to be moved.	Mean of weights required to move them.	Mean proportion.	Weights to 1 inch area.
		lbs.			lbs. oz.
Brass on wrought iron	5.90	69.55	9.510	7.312	11 12.4
Cast iron on cast iron	6.75	54.25	8.538	6.475	8 0.5
Soft steel on wrought iron	5.90	69.55	13.264	5.198	11 12.4
Brass on steel	5.90	69.55	10.584	6.592	11 12.5
Brass on brass	5.90	69.55	13.041	5.764	11 12.5
Cast iron on wrought iron	5.90	69.55	12.697	6.023	11 12.5
Cast iron on soft steel	5.90	69.55	11.139	6.393	11 12.5
Tin on tin	5.90	69.55	22.666	3.305	11 12.5
Soft steel on soft steel	5.90	69.55	10.430	6.860	11 12.5
Cast iron on hard brass	7.75	54.25	8.390	6.581	8 0.5
Wrought iron on wrought iron...	5.90	69.55	10.417	6.561	11 12.5
Brass on cast iron	6.75	54.25	8.196	6.745	8 0.5
Tin on wrought iron	5.90	69.55	11.672	5.846	11 12.5
Tin on cast iron	6.75	54.25	9.344	5.671	8 0.5

Upon the results of these experiments it is remarked,
1. That the friction of metals varies with their hardness.

2. That the hard metals have less friction than the soft ones.

3. That without unguents and within the limits of 32 pounds 8 ounces per square inch, the friction of hard metals against hard metals may very generally be estimated at about one-sixth of the pressure.

4. That within the limits of their abrasion the friction of metals is nearly alike.

5. That from 1.66 hundred weight per square inch to upwards of 6 hundred weight per square inch, the resistance increases in a very considerable ratio, being the greatest with steel on cast iron, and the least with

brass on wrought iron, their limits being as 30, 36, 38, and 44 hundred weight.

(20.) The following experiments were made with the view of determining the friction of axles. The apparatus consisted of a roller, with movable ends accurately turned, of three different metals, viz. cast iron, gun metal, and yellow brass; the pivots ran in bearings, truly bored in blocks of cast iron, leaving the axle full play, so as to prevent any binding; a cord was attached to the roller, which passed over a pulley, carrying a scale in which the moving weights were placed; the pivots projected beyond the bearing, and on these, slings were freely hung, which carried the scale, carrying the weights with which the axle was loaded. The greatest accuracy was observed throughout, the cord was the best sash line, and

the pulley very sensible; the whole descent of the body was only $4\frac{1}{2}$ inches, the time of descending is marked in the following Table.

Experiments on the friction of axles.

TABLE VI.—Of the Friction of Axles, without and with Unguents.

Gun Metal on Cast Iron.				
Weight on the axle.	Weight required to move it.	Time in passing over $4\frac{1}{2}$ in.	Proportion.	Mean Proportion.
Cwt.	lbs. oz.	sec.		
1	16 0	90	7.00	5.94
2	30 0	..	7.46	
3	44 0	..	7.63	
4	60 12	..	7.37	
5	112 0	80	5.00	
6	134 0	90	5.01	
7	154 0	..	5.09	
8	175 0	..	5.12	
9	200 0	..	5.04	
10	238 0	..	4.70	
Yellow Brass on Cast Iron.				
10	272 0	90	4.11	4.11
Cast Iron on Cast Iron.				
10	173 8	90	6.45	5.92
11	228 0	..	5.40	
Cast Iron on Cast Iron with Black-lead.				
11	161 0	90	7.65	7.65
Gun Metal on Cast Iron with Black-lead.				
11	170 0	90	7.24	7.24
Yellow Brass on Cast Iron with Black-lead.				
1	14 12	90	7.59	7.02
2	31 4	..	7.16	
3	47 8	..	7.07	
4	65 8	..	6.83	
5	84 0	..	6.66	
11	181 0	..	6.80	
Gun Metal on Cast Iron with Oil.				
11	218.8	90	5.63	5.63
Yellow Brass on Cast Iron with Oil.				
$\frac{1}{2}$	1 8	90	37.33	21.38
1	3 8	..	32.00	
2	7 0	..	32.00	
3	16 8	..	20.36	
4	24 8	..	18.28	
5	29 4	..	19.14	
10	193 8	..	5.78	
11	200 12	..	6.13	
Cast Iron on Cast Iron with Oil.				
10	131 1	90	8.54	8.67
11	140 0	..	8.80	
Cast Iron on Cast Iron with Hog's-lard.				
10	117 4	90	9.55	9.55
Yellow Brass on Cast Iron with Hog's-lard.				
$\frac{1}{2}$	1 10	90	34.46	20.99
1	3 1	..	36.57	
2	7 8	..	29.86	
3	23 0	..	14.60	
4	43 0	..	10.41	
5	47 8	..	11.78	
10	120 8	..	9.29	

Gun Metal on Cast Iron with Hog's-lard.				
Weight on the axle.	Weight required to move it.	Time in passing over 4½ in.	Proportion.	Mean Proportion.
Cwt.	lbs. oz.	sec.		
10	130 4	90	8.59	8.59
Yellow Brass on Cast Iron with Anti-attribution Composition.				
1	7 8	90	14.93	31.97
2	9 0	..	24.88	
3	10 8	..	32.00	
4	12 8	..	35.84	
5	14 8	..	38.62	
10	*190 0	..	5.89	
10	23 8	..	47.65	
10	20 0	..	56.00	
Yellow Brass on Cast Iron with Tallow.				
1	3 1	90	36.57	39.43
2	5 12	..	38.95	
3	8 5	..	40.42	
4	11 1	..	40.49	
5	13 12	..	40.72	
Yellow Brass on Cast Iron with Soft Soap.				
½	2 2	90	26.35	34.02
1	3 8	..	32.00	
2	6 0	..	37.33	
3	9 8	..	35.36	
4	12 12	..	35.13	
5	14 12	..	37.96	
Yellow Brass on Cast Iron with Soft Soap and Black-lead.				
½	5 8	90	10.18	18.55
1	9 3	..	12.19	
2	12 1	..	18.56	
3	14 4	..	23.57	
4	19 8	..	22.97	
5	23 8	..	23.82	

* In this experiment the axle had remained in a state of rest for forty-one hours, and it took 190 pounds to move it, but the axle being retouched with the composition, it required but 23 pounds 8 ounces.

Remarks on the preceding Tabular Results.

(21.) It appears when no unguents were employed, that when the gun metal was loaded with variable weights from 1 to 10 cwt., the friction varied within the limits of $\frac{1}{7.6}$ and $\frac{1}{4.7}$ of the pressure.

That the friction was greater with yellow brass than with cast iron, and the friction in all the three cases was reduced by using black-lead.

That when unguents were used with yellow brass and cast iron, the friction with the smaller weights was about one-thirty-seventh of the pressure, but with great weights of ten cwt. it increased to one-fifth or one-sixth.

That cast iron on cast iron under similar circumstances gave less friction, and still less when hog's-lard was substituted for oil.

That gun metal on cast iron gave less friction with hog's-lard than with oil.

The experiments with yellow brass on cast iron with anti-attribution composition gave very irregular results, but generally the proportion was greater with less weights than with greater weights.

That yellow brass on cast iron with tallow gave the least friction; this unguent is therefore to be recommended as the best in this case.

Manufac-
tures.

Yellow brass on cast iron with soap gave the next best result, and is therefore superior to oil

The worst result was with yellow brass on cast iron, and unguent soft soap and black-lead.

The general conclusion from all these seems to be, that the diminution of friction by unguents depends upon the weight and unguents conjointly; that the lighter weights require the finer and more fluid unguents, and the greater weights the contrary, as hog's lard, tallow, &c.

(22.) The following experiments were made to ascertain the effect of velocity on the amount of friction. For this purpose, a cast-iron roller was used, having bearings an inch wide at each end and six inches diameter, with a collar one-eighth of an inch deep, and the whole bearing surface twelve and a half square inches. A rope being wound round the cylinder, motion was communicated as in the last experiments. The whole descent of the weight was twenty-one feet.

TABLE VII.—Of Experiments on the Amount of Friction as depending on Velocity, without Oil.

	Weight on the roller.		Weight required to move the roller.		Time in falling 21 feet.		Proportion.		Remarks.	
	lbs.	oz.	lbs.	oz.						
Without Oil.	348	0	112	0	5		3.11		Began to grind. Grinding increasing with stopping.	
	300	0	112	0	5		2.67			
	280	0	114	0	7		2.45			
	280	0	114	0	7		2.45			
	280	0	228	0	4½		1.22			
	224	8	112	0	6		2.00			
	224	8	112	0	4½		2.00			
	174	8	58	0	4		3.00			
	174	8	58	0	4		3.00			
	174	8	116	0	2		1.50			
	174	8	116	0	2		1.50			
	160	8	56	0	7		2.86			
	160	8	56	0	8		2.86			
	66	8	28	0	8		2.37			
	62	8	22	0	4		2.84			
	With Oil.	62	8	22	0	4		2.84		
62		8	44	0	2½		1.42			
62		8	44	0	2½		1.42			
62		8	44	0	2½		1.42			
62		8	7	0	8.92		8.92			
62		8	7	0	11		22			
62		8	7	0	9		18			
62		8	7	0	8		16			
62		8	7	0	8		16			
62		8	7	0	8½		17			
62		8	14	0	3		5			
62		8	14	0	3		5			
62		8	14	0	3		5			
84		0	14	0	3½		7			
84		0	14	0	3½		7			
With Tallow.		84	0	14	0	3½		7		
	272	8	42	0	14		28			
	272	8	42	0	6½		13			
	272	8	42	0	6½		13			
	272	8	42	0	7½		14			

The irregularity of the resistances in the first experiments without oil, particularly the first seven, is attributed to imperfect contact and grinding of the surfaces, but afterwards the roller having obtained its bearing, and the weight in the roller scale being diminished, the irregularity ceased.

From the results of these experiments it will be seen that friction did not increase with an increase of velocity, the time in falling the whole height being double the time in falling half the height with every velocity.

(23.) *On the friction of Machines.*—1. It appears that 21 hundred weight, suspended at each extremity of a chain passing over two cast-iron sheaves of 2 feet diameter with wrought-iron axles, working in brass bearings oiled, and 12 feet 10 inches apart, was disturbed by 3 hundred weight or one-fourteenth of the total weight. In another experiment on a double crane it appeared to require one-ninth.

2. A double-purchased crane having a weight of 7057 pounds suspended to it indicated 7.62 for the friction. Another double-purchased crane indicated one-ninth.

In an experiment made on one of the corn-mills recently erected for his Majesty's Victualling Department at Deptford, it required one-tenth of the weight of the mass to overcome the inertia and friction of the bearing and tangential surfaces. In this instance the pressures of the different parts of the Machine varied from 28 pounds to 8 hundred weight per inch area, and the velocities of the surfaces from 50 feet to 120 feet per minute.

From these experiments, several important conclusions may be drawn which cannot fail of being highly useful to the practical Engineer, and several doubtful points referred to in the beginning of this Essay seem fully cleared up; that friction is independent of velocity in nearly all practical cases is fully confirmed, notwithstanding what has been frequently stated to the contrary. It appears, also, that the allowance commonly made by millwrights of one-fourth of the pressure is considerably too great, except it be while the Machine is quite new, and while the different parts have not found their proper bearing.

(24.) *Rigidity of Cords.*—As cords and ropes are not perfectly flexible, it becomes necessary in estimating the real practical advantages of pulleys, capstans, &c., to make some allowance for this want of flexibility. Before a cord or rope can act in the manner supposed in theory a certain force must be employed to bring it into close contact with its pulley or roller, and to bring it into a straight line between the two points of application; and this force, whatever it may be, is of course lost as to useful mechanical effect, and ought, therefore, to be allowed for, when our object is to estimate the actual practical power of any Machine into which ropes and pulleys enter. Experiments have accordingly been made by different persons with a view of reducing this kind of resistance to determinate laws, as in the case of friction, but certainly without the same success. In the case of friction, whether proceeding from surfaces sliding on each other, or of axles turning in their brasses or bearing, there is always a sort of ultimate degree of perfection in the workmanship of the parts which is necessary to be attained, before we can hope to arrive at any thing like a law even in this case; but when it is attained, and considering the known and fixed character of the materials, a great similarity of effect may be expected. Unfortunately, this is not the case with cords and ropes, which, when of the best construction, differ greatly from each other in their rigidity, according to the quality of the materials of which they are composed, the matter sometimes used for their preservation, the degree of twisting to which they have been submitted, their dryness, or moisture, as depending upon their exposure to weather, and even according to the state of the atmosphere when they are not openly exposed; so that we can expect to obtain but little general practical information from experiments of this kind. It will be by far the safest

Machinery
Friction of
Machines.Rigidity of
cords.

Manufactures. way, when the amount of rigidity is of importance to be known, to estimate it by experiments, at the time and on the actual rope or cord to be employed; and with a view of indicating the best way of performing such experiments, rather than with that of furnishing practical data, we propose to give a statement of one series of the experiments of Coulomb as given by him in vol. x. of the *Mémoires des Sçavans Etrangers*.

The method he pursued, which appears to be perfectly satisfactory, was as follows: having obtained two perfectly smooth and horizontal beds of timber, at a certain distance from and parallel to each other, he placed along them two rulers of hard wood well-planed, and across which was laid a well-turned roller; over this roller he hung several small packthreads whose rigidity might be considered as nothing; while thus balanced, an additional weight was added sufficient to give a very slight motion, and the amount of this weight was considered to exhibit

the resistance of the roller. He then repeated the experiment with the same weights but suspended now to different kinds of cord, and again ascertained the weights requisite to give the same degree of motion as before, and he then assumed that the difference of the two weights in the two cases was the proper measure of the cord's rigidity; and certainly for those particular ropes there can be no question respecting the assumption. The cords employed were of three kinds: No. 1. 6 threads in a yarn, or 2 in a strand, the circumference $12\frac{1}{2}$ lines, weight of a foot in length $4\frac{1}{2}$ drachms. No. 2. 15 threads in the yarn, or 5 in the strand, weight of a foot in length $12\frac{1}{2}$ drachms, and circumference 20 lines. No. 3. 30 threads in a yarn, or 10 in a strand, circumference 28 lines, and weight of a foot $24\frac{1}{2}$ drachms. The diameter of the different rollers and their weight and quality are stated in the following Table.

Machinery.

TABLE VIII.—Coulomb's Experiments on the Rigidity of Cords.

Nature of the cords.	Nature, weight, and diameter of the roller.	Weight hung on each side the roller.	Additional weight requisite to give motion.	Whole weight including the roller.	Resistance of roller previously determined.	Amount of rigidity.
No. 3. 30 threads.	Elm	100	5	315	1.5	3.5
	Diam. 12 inches	300	11	721	3.6	7.4
	Weight 110 lbs.	500	20	1130	5.6	14.4
Ditto.	Elm	200	18	443		
	Diam. 6 inches .					
	Weight 25 lbs. .					
Ditto.	Guaiacum	200	16	466	2.8	13.2
	Diam. 6 inches .					
	Weight 50 lbs. .					
Ditto.	Guaiacum	25	11	$65\frac{1}{2}$		
	Diam. 2 inches .	200	52	$456\frac{1}{2}$		
	Weight $4\frac{1}{2}$ lbs. .					
No. 2. 15 threads.	Guaiacum	25	$1\frac{1}{4}$	$101\frac{1}{4}$		
	Diam. 6 inches .	100	6	256		
	Weight 50 lbs. .	200	11	461	2.8	8.2
No. 1. 6 threads.		500	24	1074	6.4	17.6
	Ditto	100	3	253		
		200	6	456	2.7	3.3

Experiments on rigidity of cords.

There can be no doubt of the accuracy with which these experiments were performed; and no better means can perhaps be devised for ascertaining the amount of rigidity in any other cases; but we must again repeat that little or no practical advantage can be derived from the results, in consequence of the great uncertainty attending the amount of rigidity in different ropes; the experiments have therefore been given rather as pointing out one of the best practical methods of determining the amount of rigidity where it is required to be known, than as furnishing data for making allowances in any particular mechanical constructions.

In many cases it is not necessary to know the amount of rigidity independent of friction, the sum of the two being all that is requisite. Thus in the experiments we have already given by Mr. Rennie on friction, it was necessary for him to know what was the amount of friction and rigidity together, and not separately, in the pulley and rope by which his descending weight was attached, this part being altogether distinct from that friction of which he was endeavouring to ascertain the amount; and he accordingly determined the amount of this portion of the whole, by suspending equal weights on each side the pulley, and then ascertaining the weight requisite to give to the system an incipient motion, and from these results the proper deductions were to be

made in estimating the amount of friction on the other part of the system.

(25.) *On the effect resulting from the application of motive and retarding forces to Machines in motion.*—It has been shown in the preceding sections from the highly satisfactory experiments of Mr. Rennie, that the intensity of resistance to the motion of a Machine from friction, is independent of its velocity; and it hence follows, that the retardation to motion arising from this source may be combined with that arising from the resistance experienced at the working point, and that after such combination, and after the motion of the Machine has become uniform, the momenta at the impelled and working points must be equal to each other. Now the momentum at the working point is equal to the force or motive power into its velocity, that is equal to Fv . Here, however, Fv represents the power of the agent, and in many cases a part of this power is expended either in giving motion to the agent itself, or in giving motion to certain inert matter which acts upon and is external to the Machine to which motion is to be communicated. The first case comprehends the action of a spring, which, in order that it may exert any force or give motion to a Machine, must first unbend itself, and by so much force as this requires will its effective force on the Machine be diminished. And the second includes the

The effect of motive and retarding forces on Machines.

Manufac-
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case of Gravity acting on a descending weight, which weight must first be put in motion before it can give motion to the Machine, and hence the necessity of considering its inertia. The case, however, which is most obvious is when the muscular power of a man or other animal is the first mover; such, for instance, as a man pushing at a capstan bar. In this case, the man must first walk as fast as the bar moves round, and this requires a certain expenditure of his muscular force; but this alone will not render his action effective: he must also push forward the bar with what force he may have remaining over and above what he expends by walking at that rate; and the proportions of these two expenditures of force may be very different in different cases, according to the load to which he is exposed, or the velocity with which he moves. In fact, the useful result of a man's action, or that of any other animal, depends upon the weight moved, the velocity with which it is moved, and the time he can continue his exertion during a given interval, as a day, a week, or a month; so that here another term is necessary to be introduced. Calling, therefore, the weight moved w , the velocity v , and the time the man can continue his exertion t , we have wvt as the useful effect. Now it is obvious that if w is so large that the man has not power to overcome it and put it in motion, we must have $v = 0$, and consequently also $wvt = 0$, that is no useful effect will be produced, although the whole force of the man is employed and exhausted. Again, if v is so great as to require all his power to preserve it, he will not be able to move any load; so that here $w = 0$, and consequently $wvt = 0$. And if the product vw , or the velocity with which he moves, and the weight he moves, are each large; then t , if it does not entirely vanish, may become so small as nearly to reduce the effect again to zero. Seeing then that there are two actual cases in which the effect becomes zero, and one in which it approximates closely to it, whereas the whole effect increases as we recede from these extreme cases; it is obviously a highly important consideration for the Engineer to determine the proper values to be given to w , v , and t , in all cases, so that the maximum effect may be produced, either by means of theory or by practical experiment; and by the latter rather than by the former, these proportions have been determined for the action of men and horses. (Art. 4.)

We have selected this case of animal action to illustrate our remarks, but similar considerations, modified according to circumstances, attend the application of all first movers. In the case of animal exertion, we are limited by the amount of muscular power, velocity, and time; in other cases time does not enter, because natural powers may be continued indefinitely without weakening their efficacy; but other limitations step in. As for example, in a Water wheel, it is obvious we can only make the wheel move as fast as the stream; but if we make it move so fast, it is evident that no force remains to overcome any resistance; therefore, the useful effect is nothing, and the same will be the case if we oppose such a load that the stream is not able to overpower it, so that the water escapes unproductively; in this case no velocity ensues, and the effect is again nothing. It becomes, therefore, a question what resistance we ought to oppose to produce the most useful effect. Theory makes it one-third the velocity of the stream, and experiment, if it does not confirm this result, proves that the velocity must not differ greatly from this quantity. (Art. 9.)

In the Windmill the limitation arises from another Machinery cause. The quantity of surface being given, the effect will depend upon the angle at which the sails are placed, and the pressure upon them will be greatest when they are placed perpendicularly to the direction of the wind: but then there is no tendency to produce rotation, nor is there when they are placed parallel to the direction of the wind; some intermediate angle, is, therefore, to be determined, and theory gives that angle $50^{\circ} 40'$. But according to the experiments of Mr. Smeaton, although that angle gives very nearly the greatest velocity when the mill is unloaded, it does not produce the greatest effect when the load is on. The best angle, according to practice, seems to be about 72° .

In the Steam-engine we seem nearly free from all limitations; it is true, the action of the steam on the piston is diminished by the speed of the piston itself, but the velocity with which such an elastic fluid as steam rushes into a vacuum is so great, that the velocity of the piston is incomparably small in respect to it, and the limitation does not, therefore, lie there; but the nature of the engine itself steps in; we are limited by convenience to the length of the stroke, and to the velocity by the loss sustained by reciprocation, and other circumstances, so that here, also, a certain speed has by long experience been found to be better than any other for useful effect; and that speed, according to the practice of the best masters, is about 220 feet per minute.

These remarks apply to the application of the first mover of a Machine to the impelled point, or to what may be called the second mover. Velocity or rotation being obtained in this, it may be transmitted by means of interposed machinery to the working point, with a velocity the same as that of the impelled point or greater or less in any proportion. As far, therefore, as equality of motion is concerned, we may give any velocity to the working point; but here again attention must be paid to the nature of the resistance to be overcome, or which the work to be performed opposes to the action of the Machine.

Sometimes the work opposes not a simple obstruction, but a real resistance of reaction, which, if applied alone to the Machine, would cause it to move backwards, or the contrary way to that in which the power directs it; this is always the case where a heavy body is to be raised, or a spring to be bent or compressed, and in some other cases. In others, there is no such reaction, but merely obstruction: a flour-mill, a boring-mill, a saw-mill, and many other engines exhibit no reaction of the former kind; but although such Machines when at rest, or when not impelled by the first mover, sustain no pressure in the opposite direction, yet they will not acquire any motion whatever, unless they be impelled by a power of given intensity; any less force leaving them perfectly inactive. Thus, in a saw-mill, a certain force must be impressed upon the teeth of the saw, in order that the cohesion of the fibres of the timber may be overcome. This requires that a determinate force depending on the proportions of the Machine be impressed on the impelled point. Now, if this and no more be applied there, the cohesion of the wood will be only just balanced, and motion will not ensue; but if any additional force be impressed on the impelled point, the cohesion of the wood, before only just balanced, will now be overcome, and work will be performed. It is obvious, therefore, that it is only this additional force that is effective as

Manufactures. to useful mechanical agency, all the other being merely engaged in balancing the cohesion of the woody fibres. We may then, while the Machine is at work, consider it as acted upon by two forces, one urging it forward at the impelled point equal to the whole force employed, and another at the working point, acting in an opposite direction, and equal to the whole resistance furnished by the work. It is to be observed, also, that it is not merely the resistance offered by the work which the impelling force is required to overcome, it is necessary that it should overcome the inertia of all the moving parts between the impelled and working points, and the friction of all the rubbing surfaces; that is, before the necessary force can be exerted at the working point, the various connecting forces must be exerted in the different parts of the Machine; and in order that the working point may follow out the impression already made, all the connecting parts of an engine or the limbs of an animal must be moved in different directions and with different velocities; consequently, force is continually employed to produce these changes, which is altogether inefficient at the working point, being, as it were, absorbed and lost in its transit; and precisely the same remarks apply to the resistance produced by friction. Time, also, must elapse before all this can be accomplished; and in reciprocating motions in particular, a great deal both of power and time are thus consumed. Even in some which are not called reciprocating Machines, a great waste is frequently occasioned. Thus the walking crane, worked either by men or animals, acquires motion, in consequence of the inertia of the wheel, by very slow degrees; but at length the load is raised, the whole matter now in motion is to be stopped, which must also be done by degrees, because to stop it suddenly would not only shake the whole structure, but throw down the men or animals; again the motion is to be reversed, the Machine again brought to rest, and so on, obviously rendering such an apparatus very inconvenient and disadvantageous for the purpose designed. The same thing occurs, although in a less degree, in a steam-engine, where the beam and pump-rods, sometimes weighing many tons, must be made to obtain a considerably rapid motion in opposite directions twice in every complete stroke; and it must of course obtain in a greater or less degree in all engines which have a reciprocating motion in any of their parts; hence reciprocation unnecessarily introduced into any Machine is injurious, and is always avoided by the judicious Engineer.

In the application of first movers to the impelled point of Machinery, from the limited number of agents employed for this purpose, we are enabled to examine all the cases, both theoretically and experimentally, and to arrive at certain fixed principles; but in the application of the working point to the duty it has to perform, this is actually impossible. This duty may be to polish a button or to work a forge hammer of some tons weight, to grind corn, to express oil, to spin cotton, or a thousand other processes in which the questions of speed and resistance assume every possible variety of character. It would be, therefore, a mere affectation of accuracy, and tend to the degradation of Mathematical principles, to attempt to call in their aid in such cases. It is true that by assuming the amount of all the resistances, including friction, to be equal to a certain weight appended to the working point, we may reduce

VOL. VII.

Machinery. the question to a Mathematical form, and arrive at conclusions carrying on the face of them every appearance of accuracy; for the difficulty is not in the transformation of the formulæ, but in fixing the data, and as it is impossible to do this with any degree of certainty, we will not, notwithstanding the example of others, enter into any calculation on these subjects. We have considered it right to call the attention of the reader to the nature of the difficulties a Machinist has to contend with, and the views by which he ought to direct his steps in the application of the power to the work to be performed, but we will not attempt to point out to him rules for carrying his object into execution, where no certain rules can be given, and where so much must rest with his own judgment, means, and conveniences, and the certain and valuable knowledge which nothing but practical experience can bestow.

OF THE ELEMENTARY PARTS OF MILL WORK, AND THEIR CONSTRUCTION.

(26.) Before we enter upon the general description of Mill work mills under their various forms, it will be proper to treat of definitions, their detached parts, and to define many of the technical terms by which different parts are distinguished from each other,

Wheels. The general signification of the word wheel is sufficiently understood. As far as regards our present subject we have only to consider, here, those which are employed in mill work, for the purpose of communicating motion. These are *toothed wheels, cog wheels, spur wheels, face wheels, bevelled wheels, &c.*

A *toothed wheel* is generally understood to be one in which the teeth are cast or cut on the wheel itself, forming one whole.

A *cogged wheel* is one in which the teeth are supplied by pieces of iron or wood, commonly called cogs, not formed with the wheel, but inserted in its periphery, or on its face.

A *spur wheel* is one in which the teeth or cogs are on its periphery, and the term is thus applied, from the resemblance the wheel has to the rowel of a spur, the teeth taking the direction of radii.

A *face wheel* is one in which the teeth or cogs are placed round its periphery, parallel to the axis of the wheel; these were formerly very commonly employed for the purpose of producing a motion at right angles to its own; but this is now generally done by means of what are called bevelled wheels or bevelled gear.

Bevelled or mitre wheels have their teeth formed upon a conical surface, the angle of the cone depending on the angle which the axles of the two wheels make with each other; the introduction of this class of wheels into Machinery, is a comparatively recent improvement: they of course are always employed to work with others of the same form.

When two toothed wheels of different sizes work together, the largest is commonly called the *wheel*, the other being denominated the *pinion*.

Sometimes the pinion takes the form shown in fig. 8, Plate i. plate i., that is, a number of round staves are placed between two wooden or iron circular ends. It is then termed a *trundle*, sometimes a *lantern* or *wallower*.

A *fly wheel* is a large heavy disc or rim of iron, attached to some revolving part of a Machine, to give uniformity of motion.

The teeth and cogs of wheels, pinions, &c. are frequently comprehended under the term teeth; notwith-

Manufac-
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standing, when speaking with precision, those only are teeth which form a part of the wheel itself: the others, as we have already stated, are properly called cogs.

The teeth of pinions are also distinguished by the term *leaves*, and those of the trundle by *staves* or *rounds*.

The axle on which a large wheel is fixed, is called a *shaft*; but those on which smaller wheels are attached, are called *spindles*. When shafts lie in a horizontal direction, they are called lying or horizontal shafts; when vertical, they are denominated upright or vertical shafts.

The part which supports a shaft, or in which it revolves, is termed a *carriage*, when it is part of the framework; when detached, it is usually termed a *plumber block*, a supposed corruption of *pillow block*. When a horizontal shaft has a support, between the points at which the power and resistance are applied, and on which it turns, the part of the shaft which revolves on this support is called a *journal*.

The bearings for pivots or gudgeons, at the lower extremity of upright shafts, are denominated *steps*, and the parts where the journals of vertical shafts, or spindles turn, and bear against, are called *bushes*; the smaller sort, however, are commonly denoted by the word *breasts*.

Shafts are made of wood or iron; when of wood, they must, necessarily, be terminated by short iron axles, and these axles are termed *gudgeons*; the forms of which, as now generally made, will be hereafter described.

In Machinery it is sometimes necessary to convey motion to a greater distance than can be done by a single shaft; when this is the case, two or more are connected together, and this connection is called a *coupling*: when the coupling is effected by a box, into which the ends of the two shafts fit, this box is termed the *coupling box*; when there is no box, they are called *clutches* or *glands*.

Having thus defined, in general terms, the distinction which workmen have given to some of the more common parts of mill work, we must proceed to describe those parts more minutely, and the rules which must be observed in their construction.

Teeth of
wheels.

(27.) *Of the teeth of wheels.*—The figure of the teeth of wheels, is obviously a subject of great importance, and is reducible to exact Mathematical principles, and has, accordingly, engaged the attention of several very distinguished Mathematicians, from whom, as well as from ingenious practical men, many very useful principles have been introduced; some of which are described below. But here again, in order to understand the directions properly, a few definitions are required. When two wheels are working together, the number of the teeth being fixed upon, the line joining their centres is called the *line of the centres*, and if this line be divided in the ratio of the number of the teeth in each wheel, this point limits what is called the *pitch line* or *circle*; viz. a circle being described from each centre, passing through this common point, it will give two circles, and the diameters of these are called the primitive or *proportional* diameters, and the circles themselves the *pitch lines*, and the *pitch of the teeth* is the distance of them from each other, as measured across this line, as a chord, not along its circumference. These terms being explained, it will not be difficult to comprehend the direction for the form of teeth, as given below; in which we have avoided, as much as possible, every unnecessary Mathematical refinement; which has not, perhaps, in this particular case, been so advantageously employed as in many other inquiries.

It has been, indeed, demonstrated by Camus, Emerson, Young, and other eminent men of Science, that the best form of teeth is, when they take the figure of an epicycloid; but in this determination some points of practice are overlooked, and the present most general method is, to make them arcs of circles, and by increasing, as far as can be, their number, and making two or three act at the same time, a smoother and more equable pressure is maintained than could easily be effected with larger teeth, constructed according to the most accurate Mathematical rules. The equalization of motion is also still further produced in some wheels, by having two, three, or four rows of teeth on the same surface, succeeding each other uniformly, so as to ensure the continuous action of several teeth, and thus increasing the number of bearing points.

Some difference of shape is requisite, accordingly as the wheel acts against, or is acted upon, by the staves of a trundle, or the leaves or teeth of a pinion. When the wheel acts against the cylindrical staves of a trundle, Mr. Tredgold, in his edition of Buchanan's Mill Work, recommends the following construction:—

(28.) Let CD, plate i, fig. 1, be the line of centres, EE the pitch line of the trundle, and FF that of the wheel, and suppose the centre of the stave A to be in the line of centres CD; place one foot of the compasses in the centre of the stave A, and describe the arc *b c*, which is the form of the tooth. The part of the teeth of the wheel within the pitch-line may be described with circular arcs, as in the figure. The reader will easily perceive that the radius for describing the teeth is equal to the pitch, diminished by half the diameter of the stave; and also, that the centre of those arcs will always be in the proportional circle or pitch line of the wheel.

Some authors have imagined that the friction of the wheel and trundles might be reduced by making the staves revolve, but it could not be effected so far as to balance the extra labour of construction, and where the strain would be considerable, it would become quite impracticable.

Smeaton appears to have been very partial to the wheel and trundle, when the trundle was executed with cast-iron staves, which he recommended to be of an oval figure, and made smooth by grinding. It may be demonstrated, that the least real radius of the wheel should be equal to the proportional radius, added to half the pitch, when the necessary allowances are made for wear, and when the staves are of the same diameter as the thickness of the teeth. But when the staves are larger than the teeth, as in the figure, a less real radius is required.

(29.) Buchanan, in his Treatise on Mill Work, gives the following rules for forming the teeth of a wheel and pinion:—

Having set off upon the proportional circles, fig. 2, the points G Q L and O o H, according to the thickness of the teeth and leaves, draw lines from these points towards the centre of their respective circles, to serve as the sides of the spaces between the teeth and between the leaves; the depth of which spaces must be such as to give room for the action of the curved part of the teeth and leaves. Then describe upon the extremities of the sides of each tooth, epicycloids, such as Q D. L D, with the generating circle Y, the diameter of which is equal to the proportional radius of the pinion, upon the circumference of the proportional circle of the wheel as a base. The mode of forming the teeth being

Machinery.

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Fig. 1.

Fig. 2.

Manufac-
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thus shown, that of the leaves will be obvious; vv being the generating circle of their epicycloid, upon the circumference of the circle of the proportional pinion as a base.

(30.) When the teeth are small and do not begin to act till they arrive at the line of centres, the teeth of the wheel when the wheel drives the pinion, or the leaves of the pinion when the pinion drives the wheel, may be described by a circular arc, of which the radius is equal to the pitch, and of which the centre is in the pitch line of the wheel or pinion.

This method will always enable a workman to execute short teeth nearer to the true form, than any pattern tooth will enable him to do. Pattern teeth and compound curves are things that may, on some occasions, be useful: where the teeth are long and of considerable magnitude in respect to that of the wheel or pinion to which they belong. But in all the ordinary forms of wheel work, such operations must consume an immense quantity of valuable labour, to attain even the same degree of accuracy that is at once obtained by means of circular arcs.

Fig. 3.

In order to effect this, a method which is extremely simple is explained in fig. 3. The wheel being made, and the cogs fixed in much larger than they are intended to be, a circle AA is described upon its pitch diameter, and the circle BB is described within the pitch-line, for the bottom of the teeth, and a third, DD , without it, for the extremities. After these preparations, the pitch-line is accurately divided into the number of teeth the wheel is intended to have; a pair of compasses is then set to the extent of one and a quarter of these divisions, and with this radius arcs are struck on each side of every division, from the pitch-line A to the outward circle DD . Thus, the point of the compasses being set in the division e , the curve fg on one side of a cog, and no on one side of another, are described; then the point of the compasses being set on the adjacent division k , the curve lm is described, which completes the curved portion of the cog e ; and the same may be done all round, for every cog. The remaining portion of the tooth within the pitch-line AA , is bounded by two straight lines, drawn from the points g and m towards the centre, as described in the former method. This being done all round, the wheel is set out, and the cogs being dressed or cut down to the lines, will be formed ready for work, every cog being of the same breadth, and the space between every tooth and its adjacent one is exactly equal to the breadth, provided the compasses are open to the extent of one division and a quarter, as first described.

Fig. 4.

(31.) Other methods of forming teeth have been proposed; among them the following. Let the tooth a (fig. 4) press on the tooth b , in the point c , and draw the line $FCD E$, perpendicular to the touching surfaces, in the point c ; draw $AFBE$ perpendicular to FE , and let FE cut the line AB in D . It is plain, from the common principles of Mechanics, that if the line FE , drawn in the manner now described, always pass through the same point C , whatever may be the situation of the acting teeth, the mutual action of wheels will always be the same. But this construction is subject to a limitation, which must not be neglected. The teeth must be so made, that the curved part of the tooth b is acted on by a flat part of the tooth a , till it comes to the line AB in the course of its action; after which, the curved parts of a act on a flat part of b , or the whole action of a or b is either completed or only begins at the line AB , joining the centres of the wheels.

(32.) The following form of the teeth secures the perfect uniformity of action, without this limitation, but it requires very nice execution. Let the teeth of each wheel be formed by evolving its circumference; that is, let the acting face GCH of the tooth a , have the form of a curve traced by the extremity of the thread FC , unlapped from the circumference. In like manner, let the acting face of the tooth b be formed by unlapping a thread from its circumference. It is evident that the line FCE , which is drawn perpendicularly to the touching surfaces in the point C , is just the direction of position of the evolving threads, by which the two acting faces are formed. The line must, therefore, be the common tangent to the two circles or circumferences of the wheels, and will, therefore, always cut the line AB in the same point D . This form allows the teeth to act on each other, through the whole extent of the line FCE , and therefore will admit of several teeth to be acting at the same time. This, by dividing the pressure among several teeth, diminishes its quantity on any of them, and therefore diminishes the dents or impressions which they unavoidably make on each other. It is not altogether free from sliding or friction, but the whole of it can hardly be said to be sensible. The whole side of a tooth, three inches long, belonging to a wheel of ten feet diameter, acting on the tooth of a wheel of two feet diameter, does not amount to one-sixtieth of an inch, a quantity altogether insignificant.

Before leaving this subject, it will be well to describe a mode proposed by Mr. Tredgold for the construction of the teeth of two wheels, or a wheel and pinion to act with each other, in which he makes the teeth of the small wheel or pinion to represent the staves of a trundle. Let the teeth be divided as usual on the pitch-lines EE , FF , fig. 5, and on the conducted wheel C describe circles, as though they were to be staves. Conceive the centre of one of these stave teeth to be in the line of centres at A , and draw the line AB , joining the centres of the stave teeth. Then the radius Ab from the centre A will describe the curved side bc of the tooth of the conductor, and the curved part ba of the conducted wheel: and since this radius is equal to the pitch, diminished by half the diameter of the circle of the stave teeth, and as the centres will always be in the pitch-line of the wheels, all the other teeth may be easily described.

Fig. 5.

(33.) Conical wheels or bevel gear may be considered as consisting of two cones, rolling on the surface of each other: thus CD and DE , fig. 6, may be conceived to be the bases of two cones, turning on their centres, having teeth cut on them, diverging from the apex B to the bases CD and DE , but the teeth near the point of the cone being small and of little use, may be cut off at G and H . These teeth may be made of any breadth, according to the stress they are intended to bear, and this is of great importance, because by this method they may be made to overcome a much greater resistance, and work smoother than a face wheel and trundle of the old form. Besides these kind of wheels are of singular use to communicate motion in any direction, or to any part of a building, with less trouble and friction than wheels of any other construction.

Construction of the teeth of bevelled wheels. Fig. 6.

The action of the teeth of bevelled gear is exactly similar to that of common spur wheels, the diminution of the teeth towards the apex of the cone being in the same ratio in both wheels, and consequently, the same form of teeth, already described, may be adapted to

Manufac-
tures.

them. The construction, however, becomes a little more difficult: let C D, fig. 6, be a bevelled wheel, being a portion of the cone C B D, and A B its axis. Let the cone A C D be described reciprocally or having its slant height at right angles to C B D, it is evident that this cone will intersect the teeth at right angles, and consequently, that the true figure of the teeth may be represented on its surface. It may also easily be seen that the surface of this cone may be developed on a plane, by rolling it round its apex A as a centre, and that the true impression of the teeth will be thereby made. The pitch circumference C D will of course be the sector of a circle, having the slant height B C as radius.

The reverse operation then may be made use of in the construction of the teeth of bevelled gear, and Mr. Tredgold recommends that two or three pattern teeth, made in copper or any other flexible material, be in this way constructed for the larger and smaller end of the teeth.

Strength of
teeth of
wheels.

(34.) Having above described some of the most practical methods of obtaining the form of teeth, it may be proper to offer a few observations on the strength they ought to possess according to the power and resistance they have to oppose. This, however, is a simple question, for the pressure being on the pitch-line, the teeth may be considered as a beam fixed at one end sustaining a pressure at the other, therefore the length, breadth, and depth being given, the strength may be found by the principles already explained in the article on the strength of materials in our Treatise on MECHANICS, and when the pressure, and the length and thickness of the tooth are given, its breadth may be found by the following rule, when the material is cast iron.

Multiply the pressure at the pitch-line by the length of the tooth to this line in inches, and divide the product by 2544 times the square of the thickness, and the quotient will be the breadth in inches.

Thus, if the pressure at the pitch-line of a wheel is 6000 pounds, the thickness $1\frac{1}{2}$ inches, and the length 3 inches. Required the breadth.

$$\text{Here } \frac{6000 \times 3}{2544 \times 1.5^2} = 3.14 \text{ inches the breadth.}$$

It is seldom, however, that such a calculation is requisite, as generally the breadth of the teeth far exceeds what is required for mere strength. The best millwrights commonly make the breadth of the wheel and teeth about two or three times the pitch of the teeth.

(35.) The following Table is given as a specimen of the pitch and dimensions of teeth as deduced from several wheels which are actually constructed and performing satisfactorily; the horse-power and the velocity per second are also stated.

Table of the Pitch and Dimensions of Teeth, with the Horse-powers to which they are opposed.

Pitch of teeth in inches.	Thickness of teeth in inches.	Breadth of teeth in inches.	Length of teeth in inches.	Horse-power at 2.7 feet per second.	Horse-power at 3 feet per second.	Horse-power at 6 feet per second.	Horse-power at 11 feet per second.
4.2	2.	8.	2.40	13.33	17.61	35.23	64.6
3.99	1.9	7.6	2.28	13.03	15.90	31.80	58.30
3.78	1.8	7.2	2.16	10.80	14.27	28.54	52.32
3.57	1.7	6.8	2.04	9.63	12.72	25.54	46.68
3.36	1.6	6.4	1.92	8.53	11.27	22.54	41.32
3.15	1.5	6.	1.80	7.50	9.91	19.82	36.33
2.94	1.4	5.6	1.68	6.53	8.63	17.26	31.64
2.73	1.3	5.2	1.56	5.63	7.44	14.88	27.28
2.52	1.2	4.8	1.44	4.80	6.34	12.68	23.22
2.31	1.1	4.4	1.32	4.03	5.32	10.64	19.54
2.10	1.	4.	1.20	3.33	4.40	8.81	16.15
1.89	.9	3.6	1.08	2.70	3.57	7.14	13.09
1.68	.8	3.2	.96	2.13	2.81	5.62	10.33
1.47	.7	2.8	.84	1.63	2.15	4.30	7.88
1.26	.6	2.4	.72	1.20	1.59	3.18	5.83
1.05	.5	2.	.60	.83	1.10	2.20	4.03

It will be observed that the prevailing proportion in this Table is, that the pitch is 2.1 times the thickness of the tooth, and the length 1.2 times the thickness; but different masters differ considerably in these proportions, so that no very determinate rule can be given.

(36.) The relation between the primitive or proportional radii of wheels and the number and pitch of their teeth is, however, determinate, and Mr. Bryan Donkin has published a little Table, showing the several radii of wheels having a pitch of 2 inches, from 10 to 300 teeth, which is very useful; this Table we have reduced to an inch pitch, and by this means it becomes, we conceive, rather more simple. It is only necessary in this case to multiply the numbers standing in the Table opposite any number of teeth by the proposed pitch of a wheel, and the product will be the primitive or proportional radius, that is, the radius measured from the centre to the pitch-line.

The principle on which the Table is founded is obvious. If we divide 360° by twice the number of teeth, it will give half the angle the pitch subtends at the centre, and the cosecant of this angle to a radius equal to half the pitch is obviously the radius sought; we may, therefore, exhibit the rule in the following general formula:

$$\text{primitive radius} = \frac{1}{2} p \times \text{cosec } \frac{180^\circ}{\text{number of teeth.}}$$

In the following Table $p = 1$, therefore, for any other case multiply the tabular number by the pitch for the radius required.

Note. For any greater number of teeth than is given in the Table, it will be sufficiently accurate to work as for half the given number, and double the result; but for any number less than 10, it will be best to have recourse to the general formula.

Machinery.
Pitch of
wheels.

Table of the Radii of Wheels as depending on their Pitch and Number of Teeth.

Manufac-
tures.

Machinery.

Pitch of
wheels and
radii.

No. of teeth.	Proportional radius.	No. of teeth.	Proportional radius.	No. of teeth.	Proportional radius.	No. of teeth.	Proportional radius.	No. of teeth.	Proportional radius.	No. of teeth.	Proportional radius.
10	1.618	58	9.235	106	16.873	154	24.511	202	32.150	250	39.790
11	1.774	59	9.394	107	17.032	155	24.670	203	32.310	251	39.949
12	1.932	60	9.553	108	17.191	156	24.830	204	32.469	252	40.108
13	2.089	61	9.712	109	17.350	157	24.989	205	32.628	253	40.267
14	2.247	62	9.872	110	17.509	158	25.148	206	32.787	254	40.426
15	2.405	63	10.031	111	17.668	159	25.307	207	32.996	255	40.585
16	2.563	64	10.190	112	17.827	160	25.466	208	33.105	256	40.744
17	2.721	65	10.349	113	17.987	161	25.625	209	33.264	257	40.904
18	2.879	66	10.508	114	18.146	162	25.784	210	33.424	258	41.063
19	3.038	67	10.667	115	18.305	163	25.944	211	33.583	259	41.222
20	3.196	68	10.826	116	18.464	164	26.103	212	33.742	260	41.381
21	3.355	69	10.985	117	18.623	165	26.262	213	33.901	261	41.540
22	3.513	70	11.144	118	18.782	166	26.421	214	34.060	262	41.699
23	3.672	71	11.303	119	18.941	167	26.580	215	34.219	263	41.858
24	3.830	72	11.463	120	19.101	168	26.739	216	34.378	264	42.018
25	3.989	73	11.622	121	19.260	169	26.899	217	34.537	265	42.177
26	4.148	74	11.781	122	19.419	170	27.058	218	34.697	266	42.336
27	4.307	75	11.940	123	19.578	171	27.217	219	34.856	267	42.495
28	4.465	76	12.099	124	19.737	172	27.376	220	35.015	268	42.654
29	4.624	77	12.258	125	19.896	173	27.535	221	35.174	269	42.813
30	4.783	78	12.417	126	20.055	174	27.694	222	35.333	270	42.973
31	4.942	79	12.576	127	20.214	175	27.853	223	35.492	271	43.132
32	5.101	80	12.735	128	20.374	176	28.013	224	35.652	272	43.291
33	5.260	81	12.895	129	20.533	177	28.172	225	35.811	273	43.450
34	5.419	82	13.054	130	20.692	178	28.331	226	35.970	274	43.609
35	5.578	83	13.213	131	20.851	179	28.490	227	36.129	275	43.768
36	5.737	84	13.371	132	21.010	180	28.649	228	36.288	276	43.927
37	5.896	85	13.531	133	21.169	181	28.808	229	36.447	277	44.087
38	6.055	86	13.690	134	21.328	182	28.967	230	36.607	278	44.246
39	6.214	87	13.849	135	21.488	183	29.126	231	36.766	279	44.405
40	6.373	88	14.008	136	21.647	184	29.286	232	36.925	280	44.564
41	6.532	89	14.168	137	21.806	185	29.445	233	37.084	281	44.723
42	6.691	90	14.327	138	21.965	186	29.604	234	37.243	282	44.882
43	6.850	91	14.486	139	22.124	187	29.763	235	37.402	283	45.042
44	7.009	92	14.645	140	22.283	188	29.922	236	37.561	284	45.201
45	7.168	93	14.804	141	22.442	189	30.081	237	37.720	285	45.360
46	7.327	94	14.963	142	22.602	190	30.241	238	37.880	286	45.519
47	7.486	95	15.122	143	22.761	191	30.400	239	38.039	287	45.678
48	7.645	96	15.281	144	22.920	192	30.559	240	38.198	288	45.837
49	7.804	97	15.440	145	23.079	193	30.718	241	38.357	289	45.996
50	7.963	98	15.600	146	23.238	194	30.877	242	38.516	290	46.156
51	8.122	99	15.759	147	23.397	195	31.036	243	38.675	291	46.315
52	8.281	100	15.918	148	23.556	196	31.196	244	38.835	292	46.474
53	8.440	101	16.077	149	23.716	197	31.355	245	38.994	293	46.633
54	8.599	102	16.236	150	23.875	198	31.514	246	39.153	294	46.792
55	8.758	103	16.395	151	24.034	199	31.673	247	39.312	295	46.951
56	8.917	104	16.554	152	24.193	200	31.832	248	39.471	296	47.111
57	9.076	105	16.713	153	24.352	201	31.991	249	39.630	297	47.270

Construc-
tion of cog
wheels.

Fig. 7.

Fig. 8.

(37.) *Construction of Wheels.*—Cog wheels were formerly made of wood, and some are still constructed of that material; but of late years cast-iron wheels have been substituted, and found much superior in strength, accuracy, and durability. Wooden wheels are framed together in segments usually of three thicknesses, to break joint upon each other. (See fig. 7.) The middle thickness is made in six or eight pieces, and left on the inside with straight sides, *aa*, into which the arms are fitted and bolted. On each side this middle thickness another, *bb*, is placed, with break joints, and all the three are bolted together to make a solid rim, into which the cogs are to be fixed by mortises, the tenons or tails of the cogs being held in their places by a pin driven through each. The arms of wooden wheels are made in different ways; sometimes they are mortised through the shaft, and the ends are notched in the middle of the sides of the pieces *aa*, and bearing against the face of them behind, where they are bolted to them to make all fast. This manner of uniting the arms with the rim is shown at *l*, (fig. 8,) but it is not the best, because the mortises weaken the shaft very materially, and it is diffi-

cult to get such a wheel off, if ever it be required on the failure of a shaft, &c. on this account a method of doing it by what is called clasp arms is much preferable; it is shown in fig. 7. Here four arms are used, which are halved into each other, and form a frame as in the figure, leaving a square opening in the centre, and holding the rim of the wheels by their ends, which are bolted to the middle thickness of the rim, as shown in fig. 8. To fit on such a wheel as this, the shaft is made up to a square by fixing pieces of wood upon its sides, and the wheel being hung upon this is made fast by wooden wedges driven in all round; the square formed between the arms being rather larger than the shaft, by this means the wheel can be adjusted to become quite true by the wedging. Face wheels, like fig. 8, have sometimes stays or braces proceeding from the back of the rim to some distance along the shaft, where they are received in mortises, as shown by the dotted lines; these make the wheel exceedingly strong, and keep it very stiff in the square upon its axis, which is very necessary, as the action of the teeth of a face wheel with a trundle is to throw the wheel back upon

Manufac-
tures.

its shaft, which tendency these stays effectually counteract. Sometimes two sets of clasp arms are used for the same purpose, one bolted on each side of the middle thickness of the wheel by the same bolts which pass through both as well as the wheel, and unite the two sets like one of considerable depth, so that the wedging will have greater effect to keep the wheel in the square. Small wheels are frequently made of plank, solid without any arms. In this case, the middle thickness is made of four pieces, leaving a square hole between them, and they are kept together by a circular rim of segments bolted on each side all round, and the joints overlapped. The construction of trundles requires little illustration, except that they usually have an iron hoop fitted round the circular boards to prevent them from splitting. Small pinions are made out of one block of wood, and the cogs are fitted into it, much in the same way as the spokes are let into the nave of a coach-wheel.

Iron
wheels.

(38.) Iron wheels have either the teeth cast in the same piece with themselves or mortises are left in the rim for the reception of wooden teeth, according to the purposes to which they are intended to be applied. Cog wheels are found to work with less friction and noise when one has wooden and the other iron cogs. In this case, the thickness of the wooden cogs is made to exceed a little the space between them, about one-tenth of the thickness of the cog, while in the corresponding wheel the space in the same degree exceeds the thickness of the teeth. The smaller wheel is usually made with the iron teeth, and the larger one with the wooden ones. Hornbeam is found to be the best wood for the cogs, as it is not liable to split or splinter away by long wear, and is capable of taking a very smooth surface. Cogs are secured in their places by a tenon or pin driven in the inner side of the rim of the wheel. They are made larger than their final dimensions, and are dressed when on the wheel to the proper size and shape in the same way as is described for wooden wheels. Iron cogs are usually first chipped with a cold chisel and hammered to near the figure, and then filed true. Some Machinists, however, dispute the propriety of dressing iron cogs at all; they say that the exterior surface of the casting has a kind of case hardening, which is thus removed, and a softer substance of metal exposed to the acting surfaces. This is true, and the objection would have its full force, if it were possible to make castings perfectly circular, and all the cogs precisely of the same size; but as our present skill in casting iron cannot insure this, it is better to chip and dress the cogs; accuracy in the form of the teeth being a greater consideration than the quality of their substance.

Fig. 9

When iron wheels do not exceed the size of eight or ten feet, they are cast in one piece, but beyond that size there is great liability to fracture in the cooling, in consequence of the arms having a less body of metal than the rim; they therefore cool sooner, and by their contraction either separate from the rim, or bring a strain upon it which will warp it out of its true figure, and at the same time give a constant tendency to fracture upon the slightest blow or jar. For this reason the arms in larger wheels are cast separate from the rim, and attached to it by means of a flanch, which is bolted to the inner rib or flanch of the rim, as shown at *a*, (fig. 9,) which is a representation of the halves of two wheels, one being cast solid, and the other with the arms separate from the rim. When wheels exceed the size of twelve or fourteen feet diameter, it is necessary to cast them in

a greater number of pieces, as at this size the parts become so unwieldy, as not only to be difficult to mould, but inconvenient from their weight and size to fit together. The mode of connecting the parts of wheels of the larger size, viz. from fourteen to twenty and twenty-four feet diameter, is a matter of considerable difficulty, and one in which the best masters disagree. That which is most adopted, and generally considered the best, is represented in fig. 10, where the wheel is cast in five parts, the arms being in two and the rim in three. One wooden pattern serves for the three castings of the rim, and one for those of the arms. The arms are bolted together at the nave or boss by means of two lugs or projecting pieces cast upon it, *aa*, and sometimes further secured by wrought-iron hoops, *bb*, which fit into a groove cast in the boss to receive them. They are joined at their extremities to the rim in the same way as described in the last method. The portions of the rim are united by flanches cast upon their extremities at right angles to their circumference, which are bolted to similar ones in the corresponding part, as shown at *c* in the figure. Upon one of the flanches at each joint of the rim, projecting pieces, termed by millwrights *chipping pieces*, are left, by means of which they are fitted and adjusted to each other; without such pieces the fitting of the whole surface of a flanch would be a work of much difficulty and labour. Fig. 11 represents another mode of arranging the parts of a wheel, which, however, is never made use of but in those of very large dimensions. In this the boss is cast in one piece, with short arms terminated by a flanch to which the arms of the wheel are bolted. The arms are cast in three or four pieces, according to the number the wheel is intended to have; the casting consists of one arm, *AA*, and the halves of the two *BB*, *CC*, and is connected with them at the lower extremity by a flanch *DDD*, which is fitted and bolted to the corresponding one in the centre piece. The half arms are bolted to each other along their length as shown at *aa*, and are secured to the rim in the same way, as has been described for the other methods.

In some situations it is necessary to attach a wheel to a shaft which is in its place, and cannot conveniently be removed. In such cases, however small may be the diameter of the wheel, it is necessary to cast it in two halves, the same pattern serving for both castings. The two parts of the wheel may be joined at the rim and boss by the method shown in fig. 10, or by bolting them along the arms.

(39.) *On the method of hanging wheels.*—The manner of attaching or hanging wheels upon their shafts, is an operation on the accuracy of which greatly depends the perfection of mill work. Wheels are generally fixed upon their shafts or axles before the teeth are set out, or if this be not convenient they are fixed upon a temporary shaft for the purpose. Wooden wheels are usually attached to a temporary shaft, which revolves in its bearings, and by means of tools applied to the circumference they are turned to a true circle, or if they differ much from truth, a circle is marked upon the rim to which they are afterwards reduced. The circumference is then divided, and mortises are cut out for every cog, which are larger than they are intended to be, that they may be set out as above described, and reduced to their true figure without absolutely depending upon the accuracy of the mortise cut to receive them. Iron wheels, as before mentioned, are treated in a different manner; being cast in the mould of a truly circular pattern, made of

Machinery.

Fig. 10.

Fig. 11.

Hanging
wheels.

Manufactures.

wood; the cogs being cast solid with the rim, or otherwise mortises left all round for the reception of wooden cogs; in either case the rim is a true circle, and must be fixed upon the shaft exactly by its centre, instead of forming the circumference to the centre, as in the case of wooden wheels. In order to effect this, the centre hole through the iron wheel is made somewhat larger than the shaft upon which it is intended to be hung, and the space all round is filled up by iron wedges; by this means it may be set exactly true in the centre, and also in the plane that is truly perpendicular to the axis. The manner of arranging the wedges is shown in fig. 9, where eight wedges, *b b*, &c. are arranged round the shaft. It is readily seen that the wheel may by means of these be set exactly true, for by fixing a point at the circumferences, and causing it to revolve in its bearings, the inaccuracy of centring is at once detected, and, consequently the wedges at the side, which is in defect of the true or mean circumference, must be driven in, and those on the other withdrawn, until it is found that the circumference at all parts of the revolution is at the same distance from the fixed point. For the purpose of adjusting it in the square, each key way contains two keys opposed to each other, one being driven in on each side of the wheel, so that by gently driving one inwards and the corresponding one outwards, the wheel may be correctly adjusted square, or in the plane at right angles to the shaft, without altering the truth of its centring. Any error may readily be detected by revolving it on its axis, and observing the relation of the plane of the circumference to any fixed point, as in the adjustment for centring.

This is the usual method of hanging wheels, and for large wheels it is the only applicable one; there is, however, a method far superior for such wheels as are not too large and heavy to be turned in a lathe. When this is attainable, the wheel to be turned is made perfectly central on the chuck; and a circular hole, slightly conical, is bored through, into which the shaft or spindle, also accurately turned and slightly conical, is driven. The wheel while in the lathe is also turned true in the sides of the rim and extremities of the teeth, and the pitch-line is also described to mark out the teeth by, so that every thing must be perfectly true with respect to the centre: this, however, is a method only applicable to wheels of small dimensions.

Fly wheels.

(40.) *On the construction of fly wheels.*—As the advantage of fly wheels consists in the momentum generated in their rim, the greatest possible quantity of metal, usually cast iron, is thrown into it and the arms, sometimes made of wood, frequently of cast iron, and in some few instances of malleable iron. Wood is stronger than iron, taking weight for weight; but the attachments are perhaps rather better made with iron, so that commonly the arms are made of the same material as the rim, which, as is said above, is most generally cast iron; and it is only where the velocity is very great that wrought iron is at all recommended, and we are not sure whether it is any where employed. Tredgold says eight feet per second is a good velocity when the arms and rim are both cast iron; that beyond twelve feet the arms ought to be malleable iron, and that thirty-three feet is the greatest velocity that can be allowed, even with a rim of the latter material.

The construction of fly wheels is very similar to that of large spur wheels, being commonly cast in a number of pieces, which are afterwards bolted together; in the

latter, however, accuracy of fitting is the object to be attained, while in the fly wheel strength of construction is of more importance to enable them to resist the tendency to fracture they are liable to from their great velocity. Plate iii. fig. 15 represents a very common mode of constructing fly wheels; the section of the rim is rectangular, and is cast in a greater or less number of pieces, according to the diameter of the wheel; these parts are bolted together by flanches cast on each piece, as shown at *a* in the side figure. The arms are sometimes cast in two parts, and bolted together at the centre, or the centre part or boss is cast in a separate piece, with small arms, terminated by a flanch, to which the arms of the wheel are bolted, as has been already described for large spur wheels. It is usual in fly wheels to secure the boss, when the former method is used, by a malleable iron hoop, pl. iii. fig. 16, which fits in a recess left in the casting, and this being put on hot, by its contraction makes every thing firm and secure. The mode of attaching the arms to the rim is also very similar to that used for spur wheels; a recess is left in the rim of the wheel into which is fitted a flanch, cast upon the arm, and is there secured by rivets or bolts and nuts; rivets are most commonly used in fly wheels to diminish the resistance of the air, which is very considerable at the velocity with which they usually revolve. The pieces *b b* are cast upon the rim to increase the strength at that part, in consequence of the loss of metal by the recess for the arm.

Machinery

Plate iii.
Fig. 15.Plate iii.
Fig. 16.

Sometimes fly wheels are put in motion by a strap passing round their circumference, in which case they are of the shape shown in (fig. 16,) the arms are cast in two pieces with a rim, the section of which is seen in the side figure. These pieces are united at the centre by a wrought-iron hoop, as above described. The pieces *d d*, which form the groove where the strap runs, are bolted or rivetted on each side of the rim, and fit against the flanch *e e*, so as to make a fair surface, and being placed so as to break joint with each other, thus form a very strong and substantial rim.

Fly wheels are sometimes cast with arms and rim, having oval sections, in order to attain as much weight and present as little surface as possible, thereby to diminish the resistance of the air; as this resistance, as well as their friction, is a constant deduction from the motive power of the engine.

Wooden arms, as stated above, are sometimes used in the construction of fly wheels, which gives a wheel more power than one of the same weight in cast iron, as the centre of gyration is thrown at a greater distance from the axis of the wheel. The rim of the wheel under these circumstances is generally put together by a system of dove-tails, which only admit of being fitted in one direction, which is contrary to that in which the centrifugal force acts; these arms are made to fit into sockets in the rim and boss, and every thing is made firm and tight by wedges driven in at the end of the arms in the rim; this method, however, is not often made use of, not being considered so secure as those in which the arms are bolted to the rim.

(41.) *Strength of wheels.*—The strength of wheels, or that of their arms, is a simple case, immediately referable to the article on the strength of materials in our Treatise on MECHANICS. The weight acting on the wheel at the rim is the straining power, the length of the arm the lever, and the part supported by each arm is a fraction of the whole, equal to the number of arms; therefore

Strength.
wheels.

Manufactures. if w = the weight in pounds, r the radius of the wheel in feet, b and d the breadth and depth of the arms in inches, supposing them the same throughout, and n the number of arms; also denoting by a the quantity of allowable deflection; then, according to the article above referred to, or Tredgold's Essay on the strength of cast iron, we have

$$\frac{w r^3}{2656 n a} = b d^3.$$

Consequently, either the breadth or depth being given, the other dimension may be found, or the product $b d^3$ may be found, and each dimension determined. As an example, let us propose a wheel of 6 feet radius, the number of arms 8, the weight acting at its circumference 1600 pounds, and the deflection allowed one-tenth of an inch: then

$$b d^3 = \frac{1600 \times 6^3}{2656 \times 8 \times .1} = 163.$$

Hence, if we make the breadth $2\frac{1}{2}$ inches, then

$$d = \sqrt[3]{\frac{163}{2.5}} = 4.03 \text{ inches the depth.}$$

Frequently, however, the arms are made less deep towards the rim than towards the axle, where the strain is greatest. When this is intended, the number 1640 is to be employed in the denominator, and the result will give the breadth and cube of the depth at the axle. If a wheel be strained till the arms break, the fracture takes place near the axle; it is proper, therefore, to strengthen them about these parts by the metal saved by reducing them near the rim.

Shafts. (42.) *Of shafts.*—These are made of either wood or iron, but at present the latter material, either cast or malleable, is most generally employed. When large wooden shafts are used, they are made either of one large log of oak, or built of fir, with gudgeons inserted into their extremities, in the manner described in a subsequent page. We shall here, however, only speak of those made of cast and malleable iron. Shafts of the larger kind are commonly of cast iron, and their forms are square, solid, cylindrical, or tubular. Wrought-iron shafts and spindles are however generally employed in the smaller Machines, being less liable to fracture than small cast-iron rods, from the blows to which all Machinery is more or less exposed from accidental circumstances. Perhaps large shafts would be for the same reason more commonly made of wrought iron than they are, if it were not for the difficulty of forging them, and the consequent expense attending their use. But whatever may be the material and the shape of the shaft, the journals which revolve in the bearings must be cylindrical, and turned true in a lathe, so that commonly in treating of the strength of shafts having journals, they are the latter only which require to be considered, these being generally less than the shaft, but in other cases we must compute the strength of the shaft itself.

Strength of shafts. (43.) *The strength of shafts.*—This is a question of considerable importance to the practical millwright, but it is one perhaps in which former practice is a better guide than theoretical computation. It has however engaged the attention of scientific men, and Mr. Tredgold in particular has made some valuable deductions; and when his results differ from the usual practice, it is generally on the side of safety.

Machinery. There are different circumstances to be considered in reference to shafts. They have sometimes, as in the case of a water wheel, to support a great weight, independently of the strain thrown upon them by the power and resistance; this will have a tendency to produce deflection, which deflection must be first provided against, and must not exceed $\frac{1}{12}$ th of an inch to 12 feet length. Now if the dimensions requisite to give this transverse stiffness be greater than is required for the twisting power brought on at the circumference, this latter need not be regarded. But in other cases, as in vertical shafts, there is little or nothing of this transverse strain, and the effect of torsion is all that need be considered. Again, in long shafts having a journal, with the power acting at one end, and the resistance at the other; it is not sufficient to provide strength to prevent actual fracture, we must have sufficient dimensions to prevent twisting beyond a certain quantity; and in the latter case it is not so much the shaft itself, which is commonly square, that is to be considered, as the journal, which is necessarily cylindrical, and liable to wear.

As far as regards the strain first alluded to, it has been already treated of under the article *Strength of Materials* in our *Treatise on MECHANICS*. We shall, therefore, only consider that force which has a tendency to destroy the shaft by torsion, here also confining our inquiries entirely to the three following forms, namely, square, solid, cylindrical, and hollow cylindrical shafts, and to the two materials of cast and wrought iron.

It is shown by Mr. Tredgold in his *Treatise on the Strength of Iron*, that if r = radius of a wheel in feet at the circumference of which the power is applied, s the side of a square, or d the diameter of a shaft in inches, t the thickness of metal in a hollow cylinder, and w the weight in pounds, that the following are the equations of condition, viz.

In Cast-iron Shafts.

Square $r w = 150 s^3$
Solid cylindrical . . $r w = 125 d^3$
Hollow cylindrical . $r w = 125 d^3 (1 - p^4)$.

In Wrought-iron Shafts.

Square $r w = 168 s^3$
Solid cylindrical . . $r w = 140 d^3$
Hollow cylindrical . $r w = 140 d^3 (1 - p^4)$.

Where $p = \frac{d - 2t}{d}$.

But, as in practical cases the question is generally the side of the square, or diameter, these are best converted into the following forms:

Cast Iron.

Square $s = \sqrt[3]{\frac{r w}{150}}$
Solid cylinder . . . $d = \sqrt[3]{\frac{r w}{125}}$
Hollow cylinder . . $d = \sqrt[3]{\frac{r w}{125 (1 - p^4)}}$

Wrought Iron.

Square $s = \sqrt[3]{\frac{r w}{168}}$

Manufactures.

Solid cylinder. . . $d = \sqrt[3]{\frac{r w}{140}},$

Hollow cylinder. $d = \sqrt[3]{\frac{r w}{140(1 - p^4)}}.$

These, however, will apply only to very short shafts in which the angle of torsion is small and may be disregarded.

Strength of long shafts.

(44.) When the length exceeds more than one-fourth the radius of the wheel, at the circumference of which the power acts, the twisting effect must be taken into account; and Mr. Tredgold has shown, that in such a case, the shaft being cylindrical, the only necessary form to be attended to, we have

$$d = l^2 \left\{ \left(\frac{r w}{5.2 l^3} + 5184 \right)^{\frac{1}{2}} - 72 \right\}.$$

Or in words, multiply the weight in pounds by the radius of wheel in feet, and divide this product by 5.2 times the cube of the length in feet. To the last quotient add 5148, and from the square root of the sum subtract 72. This remainder multiplied by the square of the length, also in feet, will give the diameter in inches.

Suppose, for example, it were required to find the diameter of a shaft for a water wheel, the length of the shaft from the water wheel to the cog wheel being 6 feet, the radius of the water wheel 9 feet, and the greatest force it will be exposed to 2000 pounds.

Here $\frac{9 \times 2000}{5.2 \times 6^3} = 16$ nearly,
 $\sqrt{16 + 5184} = 72.12$
 Subt. 72
 .12

Then $.12 \times 6^2 = 4.32$ inches diameter.

Generally, however, practical men estimate the resistance, or rather the size of their shafts or journals, by the number of horse-power and the speed of the fly wheel, that is, the resistance is supposed to be as the horse-power directly, and the revolutions inversely; for, with a given power, the velocity will be greater as the resistance is less. And according to this measure Buchanan gives some Tables and Rules, derived from shafts already constructed and of acknowledged good proportions, which he divides into the three following classes: viz. 1st class, steam-engine fly-wheel shafts; 2d class, those in immediate connection with water wheels, or other heavy work; and 3d class, for ordinary internal mill work, and the rule for finding the diameters is as below.

1st class, $d = \sqrt[3]{\left(\frac{h}{n} \times 420\right)},$

2d class, $= \sqrt[3]{\left(\frac{h}{n} \times 200\right)},$

3d class, $d = \sqrt[3]{\left(\frac{h}{n} \times 100\right)},$

where d is the diameter in inches, h the number of horse-power, and n the number of revolutions per minute.

Lateral strain and twisting of shafts.

(45.) We have already stated, that when a wheel is exposed to more than one strain, it will be necessary, and it will be sufficient, to provide against the greater of the two. On this subject, the following remarks of

VOL. VII.

Mr. Tredgold are important; they are given in his edition of Buchanan's Essays on mill work. Machinery.

All shafts are liable to lateral stress and twisting, but it will commonly happen that one of these forces will vastly exceed the other: and, consequently, we need only adapt the shaft to the resistance of the greater power; but, in the first place, we must be able to ascertain when the one or the other must be calculated for.

The resistance of a shaft to a lateral strain must obviously be measured by its stiffness to resist flexure, because it would otherwise play too much on its brasses, couplings, &c., and occasion irregular action in the Machine. From a comparison of shafts in use, it appears that about one-hundredth part of an inch for each foot in length is the quantity of flexure that may be allowed without sensibly affecting the regularity of the motion. In a cast-iron shaft, supposing it to be a solid cylinder, if w be the stress in pounds, when referred to the middle of the length of the shaft, l = the length in feet, and d = diameter in inches, the deflexion in the middle being $\frac{l}{100}$ of an inch, then $\frac{w l^2}{250} = d^4$ or $w = \frac{250 d^4}{l^2}$. (See the Author's Essay on cast iron, Art. 218.)

Now if $\frac{740 h}{v}$ be the twisting power collected at the surface of the shaft, where v is the velocity of that surface in feet per second, and h the greatest number of horse-power that is necessary to work the train of Machinery to which the shaft belongs, we have

$$124.8 d^2 = \frac{740 h}{6 v};$$

but the velocity of the surface of the shaft is equal to its circumference in feet, multiplied by the number of revolutions in a second. And if this number of revolutions

be n , then $v = \frac{11 n d}{42}$; and the equation between the

stress and strain reduces to $d^3 = \frac{3.78 h}{n}$. It therefore

appears, that when $\left(\frac{3.78 h}{n}\right)^{\frac{1}{3}} = \left(\frac{w l^2}{250}\right)^{\frac{1}{4}}$ the strain from torsion will be equal to that from lateral pressure,

whence if $\frac{1472}{l^2} \times \left(\frac{h}{n}\right)^{\frac{4}{3}}$ be less than w , the diameter

of the shaft must be determined by the rule for lateral stress, and if it be greater than w calculate the diameter by the rule for torsion. For the advantage of those who are not much versed in calculation, it may be of use to remark, that in common cases when the stress in pounds, multiplied by the square of the length in feet, is less than 3000, the twisting strain will be greater, and the contrary.

In a series of lying shafts, it is necessary to make the journals equal to the twisting, with the addition of the necessary allowance for wear, and it will, therefore, often be necessary to adjust the shaft to both strains. But in all instances where the lateral strength is less

than $\frac{1472}{l^2} \times \left(\frac{h}{n}\right)^{\frac{4}{3}}$ the bodies of the shafts need not be greater than the journals

Q

Manufac-
tures.
Couplings.

Coupling-
box.

Couplings
for two
bearings.

Plate ii.
Fig. 1.

By Mr.
Murray.
Fig. 2.

(46.) *Of Couplings.*—The conveyance of motion by the connection of shafts would be a matter of great simplicity, if it were possible to construct Machinery mathematically true, and if their supports were not liable to settlement, and their parts secure from wear and tear. But in practice, it is found from these causes to involve some difficulty, and, accordingly, a number of different methods have been proposed.

Of these the most simple is to make the ends of the shafts square, and to employ what is called a square coupling-box, of exactly the same interior dimensions as the ends of the shafts into which the latter are fitted, so that when one shaft is put in motion the box connects them in such a manner that the two must revolve together; but when occasion requires it, the box may be slipped back upon one shaft, and the other disengaged or removed, either for the purpose of discontinuing the motion or for repair.

If the axles of shafts could be brought practically into a straight line, and the square ends made and fitted to the box with perfect accuracy, the motion would evidently be smooth and continuous, but in large Machinery this is impossible; and even if it were possible this perfection would not continue long, in consequence of the wearing of different parts, and the unavoidable settlements that too commonly occur. As soon as either of these happen the shaft is in some part of its revolution lifted off the bearings, thus producing an unsteady motion, with considerable straining and wearing of the couplings, by which they in their turn suffer and produce a further evil.

For these reasons the square coupling-box has been a good deal abandoned in mill work, although it is still used in smaller Machines, where it can be executed with greater accuracy, and is not liable to the same evils as in larger works. However, even in small Machines, the square coupling has been in many cases supplanted by the cylindrical box, in which two pins at right angles to each other are inserted through the box and shaft to connect them together. Here there is no wear, except in the holes and pins, which latter can be easily replaced, and greater accuracy in the fitting may be attained, because both the shaft and the box may be turned in a lathe, and thus fitted to each other with the utmost precision.

(47) It is proper to observe also that couplings in general are more easily applied when each shaft has two bearings, but sometimes one of the shafts has but one, and in these cases the boxes above described are very commonly employed, at others a scarfed joint is used, and the parts bolted together. Various other means are likewise adopted in different Machines, which will, however, be more appropriately given in the explanation we shall have to offer of them individually.

When a shaft has two bearings, a very usual mode of coupling is represented in plate ii. fig. 1. Here the shafts are terminated with circular heads, one having teeth and the other corresponding indentations to receive them, and thus one is made to give motion to the other; while if any slight settlement of the building, or other cause, depress one of the bearings, or raise another, so as to put the two shafts out of the perfect straight line they ought always to preserve, these joints will admit the slight flexure and still communicate steadily the motion of the one shaft to the other.

In fig. 2 and 3 is represented a coupling-box first used by Mr. Murray, of Leeds, for connecting a long line of

shafts which have to carry a heavy strain. It is so formed that it communicates the motion in the manner of an universal joint, should the shafts be out of line. Let A and B be the two shafts to be united; C D their necks, or collars, which lie in the bearings; the ends projecting beyond these have boxes, E F, fixed on them either by a square with wedges, or by a round part with a fillet; one of these boxes, E, has a piece projecting from the inside of it on each side, and extending into the other box, as is shown at *a a*, (fig. 3,) which is an inside view. The box F has two similar pieces projecting from it at *b b* into the other box E; within the boxes an iron cross, *c c, d d*, is situated, it has screws fixed into the end of the arms, and by these the motion is communicated: thus the pieces *a a*, when the shaft A and box E are turned round in the direction of the arrows, act against the screws *c c* of the cross, and cause them to revolve, at the same time the other two screws *d d*, at the other arms of the cross, press against the pieces *b b*, which belong to the box F and shaft B, thus putting them also in rotation. The cross is placed quite detached in the boxes, and thus acts as a universal joint to communicate the motion of one to the other; the screws *c c, d d*, at the end of the cross, are only made use of in order that the acting points may be of steel, which may be made smooth, so as to have but little friction.

Another mode of uniting shafts, by Mr. Murray, is shown in fig. 4; this has the advantage of requiring only one bearing for every length of shaft, whereas that above described requires one at each end of every length. A and B represent the two shafts, each having a pivot formed at the end; these pivots are fitted into a coupling piece C D E, which is bored inside to receive the ends of the shaft, and turned outside with a neck D D, which works in a bearing; the two shafts, A B, are connected with the coupling piece D, at C and E, by means of a cross key *l m* put through each shaft, and the ends of them are received in notches made inside the coupling piece at C and E, where it receives the end of the shafts. It is to be observed, that the shafts do not fit tight in these pieces E and C, but only in the pivots *a b*, by which means they have a little freedom of motion, and this without straining the bearing in which D runs, because it is only the short coupling piece which is received therein; and, consequently, a slight deviation from the straight line will have no tendency to produce any injurious strain.

(48.) *The universal joint*, called also *Hooke's joint*, from the name of its inventor, Dr. Hooke, furnishes another method of uniting shafts which are inclined to each other. This contrivance is shown in fig. 5, where A and B are two shafts, the ends of which, within the bearings C and D, are formed in the shape of a fork. G is a circular iron ring, with four pins or pivots, *a a a a*, on its circumference, which fit into holes in the ends of the forks, by that means uniting them together, and at the same time allowing freedom of motion. In this way rotary motion may be conveyed from one shaft to another when they have considerable inclination; still, however, if the angle of the shafts be more than 15 degrees, it is advisable to use bevelled wheels, as when so much inclined, the universal joint works with great friction and irregularity of motion.

(49.) Fig. 6 is a method of coupling shafts, called the friction coupling, where the connection depends simply upon the contact of surfaces. It cannot, perhaps, be so well applied to heavy Machinery, but there are a variety of

Machinery.

Coupling
by a uni-
versal joint.

Fig. 5.

Friction
couplings.

Manufactures. circumstances where it can be used with more advantage than any other method. One of the shafts, A, has a circular plate cast upon the end of it, which fits into a loose box upon the end of the other shaft B; *b b* is a collar of leathers which fits within the enlarged end of the shaft B, so that when the nuts *a a* are screwed up, it causes the box D to press against the collar of leathers, and by its friction puts the shaft B in motion. A collar of leathers is also sometimes placed at the end of the shaft, as shown at *c*. This method is highly to be recommended in a variety of Machinery, particularly in turning and boring Machines, where it can be screwed so as just to have sufficient friction to carry on the work with its ordinary resistance; but so little beyond it, that should any accident happen, such as a tool getting foul, or any thing getting entangled with the Machinery, the additional resistance will stop it, the other part continuing its rotation, and by that means often preventing not only damage to the work under operation, but injury to the workmen themselves.

In the above description of coupling shafts together, we have confined ourselves principally to those which are intended to be permanent; other methods are employed in cases where it is necessary to engage and disengage Machinery in the course of its operations; these are described below.

Methods of engaging and disengaging Machinery. (50.) *Of the Engagement and Disengagement of Machinery.*—In the numerous contrivances for this purpose the particular object aimed at has been to communicate motion without a shock; as in consequence of the inertia of bodies, or their disposition to remain in the state in which they are, the parts of Machinery when acted upon too suddenly by a moving power, are liable to fracture and disarrangement. The inventions for this purpose may be divided into two classes, *viz.* when the motion is communicated by bands, belts, or chains, and when it is communicated by wheel work; the former generally possesses the advantage of bringing on the motion more gradually, although the application to large Machinery is attended with inconvenience.

by fast and loose pulley, Fig. 7 represents a contrivance, termed the fast and loose pulley, which is remarkable for its simplicity. It is attended with no shock, and is considered the most perfect method yet invented for the purpose where it can be applied. It consists simply of two pulleys, B and C, one being fixed on the axle, and the other loose, and the belt or band which conveys the motion may be shifted at pleasure, either upon one pulley or the other; by that means putting in or out of motion the axle A. It may be proper here to mention, that in order to make a belt run properly on a pulley, it is necessary to have the rim a little rounded or swelled in the middle. The belt always inclines to that part of the pulley which is of greatest diameter. This curious property is of great practical use, and until it was known, it was found very troublesome to prevent belts slipping off the pulleys.

by a gland, Fig. 8. Another very common contrivance for disengaging and re-engaging a Machine moved by a belt or band is shown in fig. 8, where the pulley P revolves upon a shaft A B, to which it is occasionally required to be connected, in order to convey motion to the Machinery. To effect this, the axle has a cross piece or gland, D E, firmly attached to it, and upon the wheel, which is made free to slide upon the shaft, one or more projecting pieces or teeth are cast, so that when, by means of the handle F G, the wheel is moved towards the gland, the projecting teeth engage the limbs of the gland, thereby

carrying it round, and with it of course the axle A B, to which is attached the Machine intended to be put in motion. This contrivance is however attended with a shock which renders it very inferior to the last mentioned. There are besides these a great number of other methods used by different masters when motion is conveyed by straps; but as they consist of a variety of forms of the same principle, it is not necessary to enter into a further description of them. Let us, therefore, next endeavour to describe some of the methods made use of when motion is conveyed by wheelwork.

(51.) When a mill is in motion, we may with perfect safety throw wheels out of gear; but in throwing them in gear, there is great danger of breaking the teeth, particularly at high velocities, so that such a method of disengaging and re-engaging when motion is conveyed by wheelwork can only be employed in such Machines as rolling mills, and a few others, where the velocity required is very slow.

A method which is more commonly used, and is more applicable to the generality of Machinery, is shown in fig. 9, where A B represents a shaft to which is attached the Machinery required occasionally to be put out and in motion, and C C a wheel which is made to revolve freely upon it by means of a bush, and which is always in motion from the millwork. The part of the shaft marked A is square, and the clutch D D is made to slide freely upon it by means of the handles E F, so that it may be readily put in motion by engaging it with the revolving wheel C C. In this method, also, a considerable shock is given to the Machinery when the connection is made; but there is no liability of fracture, as the teeth of the clutch may be made of any thickness.

A mode of disengaging and re-engaging, termed the *locking bayonet*, is sometimes preferred. The construction is as follows: strong arms, A A, fig. 10, are fixed fast on the shaft R just before the wheel, either by a circular fitting with a fillet by a square, or they may be cast upon it; through the extremities of these arms holes are drilled to receive the shanks, *ff*, of the locking bayonet, which are fixed fast by nuts to an arm D D, very nearly similar to A A, but it slides upon the shaft, and has a central part, *g*, with a circular groove round it, in the manner of a pulley. A fork, embracing the central piece in the groove, gives the means of sliding the bayonets *ff* and D upon the shaft, so that the points of its shanks intercept the arms of the wheel, and carry it round with them and the shaft; but when the points of *ff* are drawn back clear of the arms of the wheel, it revolves freely without turning the shaft.

In consequence of the defects attending this as well as the former mode of connection, that is, the injury done to the Machinery, several other attempts have been made to invent one where the motion may be brought on more gradually; and have indeed been attended with considerable success in the method termed the *friction clutch*, which is shown in fig. 11. Here A B is the part of a shaft kept in motion by the mill; C D E a bayonet, which either slips on a square part of the shaft A B, or passes through the arms of a cross H I, (as represented in the figure,) which cross is fastened to A B. F G is part of the shaft to be connected with A B; upon F G a kind of drum or pulley is fastened, with a hook, L M on the outside, which by means of screws at *a a* is made to press gently upon the surface of the drum. In setting the Machine in motion, the hoop L M is carried round by the bayonet or clutch C D E, and by

Manufac-
tures.

the friction of the hoop upon the drum brings it into motion in the same easy and gradual manner that a belt does a Machine which is driven by a pulley; but the hoop is found to answer better when it is made to act as a spring upon the drum. There is a great deal of ingenuity in this contrivance, it may be applied to large Machinery, and variously modified according to circumstances, and it is obvious also that it prevents the shock or strain upon the Machinery which is the objection to the other methods. It may likewise prevent injury to the mill itself, arising from belts getting foul, or from chips, &c. falling in among the teeth of wheel-work; for in most cases of this kind the hoops would slip upon the drum and allow that part of the Machinery to stop without sensibly altering the general motion of the mill, while with the common method the whole motive force of the mill would continue to be exerted, and would probably fracture or strain some part of the Machinery before the accident might be discovered.

Gudgeons.

(52.) *Gudgeons*.—It is always desirable that gudgeons should be formed of the same piece as the shaft, because the slightest deviation from the straight line causes them to strain and work very irregularly in their bearing. In wooden shafts this is, of course, impossible, and is one of the chief objections to their use. When it is considered that the direction of the stress which tends to loosen a gudgeon in a wooden shaft is continually changing, and that such action is exerted upon wood, a material that is so very easily and permanently compressed, it will not be wonderful that it should have been found difficult to render them firm and lasting; and before the improvement called the cross-tailed gudgeon, the prevention of their becoming loose in the shafts was attended with great trouble and expense.

Cross-tailed
gudgeon.
Plate iii.
Fig. 1, 2.

A cross-tailed gudgeon is represented in plate iii. fig. 1 and 2, which is made of cast iron, and turned true; it has four leaves, *a b c d*, forming a cross, which are let into the end of the wooden shaft *A*; the front edge of each leaf is considerably thinner than the back, so that a pair of strong iron hoops, *h h*, being driven tight upon the end of the shaft, closes the wood round the cross and holds it fast; the back of the leaves being also wider than the front, it will not come out. As an additional security, screws are sometimes put in through holes in the arms of the cross, which are in that case made thicker, and do not go so far into the wood. The screws go into the timber a considerable distance, where a mortise is cut into the wood to meet the end of the bolt, and an iron nut is dropped in which is screwed upon the end of the bolt by means of a spanner. By this contrivance, a gudgeon may be fitted into a wooden shaft very fast, but still it will never come into competition with iron shafts where the gudgeon is made in one solid piece with the shaft itself.

Another
form of
gudgeon.

Fig. 3, 4, 5.

An improved method of fixing gudgeons is described in the *Transactions of the Society of Arts*, vol. xxxi. p. 223; it consists in casting the gudgeon with cross arms, which fit into proper notches in an octangular box of cast iron, which has been previously fixed on the end of the shaft. *A A* (fig. 3, 4, 5) represents a portion of the end of the wooden shaft, which is of an octangular form, and has the water wheel fixed upon it; it is long enough to reach across the pit in which the wheel works, and having a gudgeon at each end, is supported and revolves upon them in proper bearings.

B B is the cast-iron box fitted fast upon the end of the shaft, and being wedged tight prevents the wood from splitting as effectually as any hoops can do; upon the end of the box is a projecting flanch *a a*, and in the face of this, four grooves or notches are made for the reception of the arms of the iron cross *b b, d d*, which is part of the gudgeon *c*, on which the shaft revolves; this cross is firmly attached to the box by four screw bolts, which pass through the flanch, and also through the ends of the arms of the cross, having nuts screwed on the outside to make all fast. The section (fig. 5) shows the cross piece and box separated to explain the manner of fitting them together, the inside face of the cross having projections *e e*, which enter the end of the box, and keep the pivot in its true centre; thus the bolts have only to hold the gudgeons fast on the end of the box, the principal strain being taken off by this manner of fitting the cross into the box. When the gudgeon of a wheel fitted on this plan becomes worn out so as to require replacement, it can be removed by taking off the four nuts, and a new one applied; the gudgeon also being of small dimensions, it will admit of its cylindrical part being very conveniently turned in a lathe, which is a considerable advantage.

In vertical shafts, where their own weight, as well as that of the Machinery attached to them, is supported by their lower extremity, this method is greatly preferable to the cross-tailed gudgeon, as it affords support to a greater surface of wood. For lying or horizontal shafts, there is no method, at present introduced, preferable to the cross-tailed gudgeon.

(53.) When an iron shaft is cast solid, the gudgeon is formed in the same piece with it, differing from the other part only, in being generally smaller, and turned truly circular, in a lathe. The necessary strength of gudgeons will be considered in a subsequent page, although in most cases, in practice, they are made larger than their strength requires, as the wear and tear of small ones, as well as the brasses in which they revolve, is very great. In vertical cast-iron shafts, the pivot is usually cast somewhat in an egg shape, being rather smaller at *a*, (fig. 6.) to prevent it from binding in the step; another mode is, to terminate the shaft flat at the lower end, having a small oblong recess in it. To this end is fitted a round piece of steel, *A*, fig. 7; flat below, except having a groove, *a*, across it, similar to that in the head of a screw, the use of which is to feed it regularly with oil. A pivot or step, on this construction, was presented to the Society for the Improvement of Arts, and was said to have been twenty years in use, in a horse mill, without being perceptibly worn. It has been since applied in the case of heavy upright shafts, where other means were found inadequate to prevent the action of the pivot, and has given great satisfaction in its use. It is to be observed, however, that it does not answer so well in cases where there is much lateral pressure, and a better mode is now in use in several mills. This consists in having the steel pivot made cylindrical, and fitted into the foot of the upright shaft. The bottom of the step is made convex, and there is interposed one or more pieces of steel, formed like a double convex lens: these pieces of steel, having a little motion, make the relative motion of the pivot less, and consequently diminish the friction. We may also add, as an entirely different method, that Mr. Bramah, in the specification of his patent for Machinery for surface planing, includes a mode of running pivots entirely on a fluid, and raising and depressing

Machinery.

Fig. 5.

Gudgeon to
solid iron
shaft.

Fig. 6.

Fig. 7.

Manufac-
tures.

them at pleasure, by means of a small forcing pump and stop cock. This method, however, has not been brought into general use, but is practised, in some cases, as in the Planing machine in the Royal Arsenal, Woolwich.

Gudgeon
for hollow
iron shafts.

Fig. 8, 9.

(54.) The best shape to give strength to cast-iron shafts, is tubular or hollow cylindrical, in which, of course, it becomes necessary to make the gudgeon in a separate piece, which is some inconvenience. This, however, can be attached to them in a much firmer manner than in wooden shafts, and if executed in a good workman-like way, will last for a great length of time, without any deviation from truth. A B (fig. 8 and 9) is a section of a cylindrical shaft, at each extremity of which the metal is left thicker for some distance, and three ribs, *a, a, a*, cast upon it, having key ways left in the face of them; *cc* is the gudgeon, which has three arms or feathers, cast or wrought upon it; having also key ways left in their faces, which correspond with those on the ribs, in the end of the shaft. A wrought-iron hoop, *h*, is then put on the end of the shaft, to prevent it from splitting, and the gudgeon being adjusted in its place, is driven tight by keys or wedges. The gudgeons are sometimes made with four arms, but it is not considered good, because, in driving the keys, it is difficult to make them all bear alike; whereas, they necessarily must bear alike with three arms; for in driving one key, the other two must be tightened also. In the smaller hollow shafts, the gudgeons are usually made without arms, being a solid cylinder, having key ways cut in three places on its surface; this fits loosely into the end of the shaft, and is made tight by keys, as in the other method. Gudgeons are sometimes turned after they are secured in the shafts; but, in ordinary cases, sufficient accuracy is obtained by turning them before they are attached, which is most convenient, and then adjusting them, by the keys, centrally with the shaft.

Fig. 10.

A mode of securing gudgeons, best suited to vertical cast-iron shafts, is represented in fig. 10; where A B C D is part of the end of a shaft, which is bored out truly circular, and the gudgeon turned true, to fit it; a circular flanch is cast round the extremity of the shaft, which sets against a similar one in the gudgeon, and is secured to it by screw bolts and nuts, as seen at *a a*, in the figure. This method involves a great deal of workmanship, and is consequently more expensive than the one described above. The pivot is sometimes made of steel or wrought iron, and being turned slightly conical, is fitted into the gudgeon, as shown by the dotted lines in figure 9; so that in circumstances where pivots are liable to a great deal of wear from grit, &c., as in the case of the gudgeons of water wheels, they may, at any time, be easily replaced.

(55.) *Strength of Gudgeons* — Gudgeons having all the weight of their shaft, wheels, &c. to support, ought to be made sufficiently strong for that purpose; while to avoid unnecessary friction, their diameter should be as small as possible, consistently with the liability to wear, and convenience of workmanship.

The strength of a gudgeon is limited by the strain Machinery. it will bear, without permanent derangement of its structure, as the length is always so small with respect Strength of to the diameter, that the flexure will be, in all practical gudgeons, cases, insensible; and the calculated stress should include every kind of force acting on the axle or shaft; the diameter should also be determined, so that the gudgeon may be capable of resisting the whole, if it were thrown on the extreme point of its bearing.

If *w* be made to represent the utmost amount of the stress in hundred-weights, and *l* the length of the gudgeon, in inches, from the shoulder to the extreme point of bearing; it is shown (Tredgold's *Essay on Cast Iron*, Art.

138) that $\frac{(112 w \times \frac{1}{12} l)^{\frac{1}{3}}}{5}$ or $0.42 (w l)^{\frac{1}{3}} = d$, the

diameter of the gudgeon in inches. But an allowance should be made for wear, which will be nearly directly as the stress, and inversely as the length of the bearings; consequently, the length of the gudgeon should be greater, in the same ratio, as the stress is greater. And until some more certain principles be found of proportioning the gudgeons of a Machine to the nature of its service, we may allow one-fifth of the diameter as a provision against wear, when no gritty substance is likely to affect them; and one-third in all cases where they are exposed to gritty matters. In the former case, the rule will become $\frac{1}{5} \sqrt[3]{w l} = d$, or $0.5 (w l)^{\frac{1}{3}} = d$; that is, multiply the stress in hundred-weights by the length of the gudgeon in inches, and the cube root of the product being multiplied by 0.5 will give the diameter of the gudgeon in inches; and in the latter, when the gudgeon is likely to wear much, from the nature of the Machine, or its particular situation, multiply the cube root of the product by 0.56, instead of 0.5.

Buchanan, however, states, that it is found, from observation, that in actual practical cases, the cube root of the weight in hundred-weights gives very nearly the diameter of the gudgeon in inches, which is a very simple rule.

(56.) The following Table is a statement of the proportions of the gudgeons of several water wheels, in actual service and which have been found to give satisfaction in their working. The 1st column contains merely the ordinal numbers. 2d shows the material of which the wheel is made. 3d the diameter in feet. 4th the width in feet. 5th the description of wheel. 6th the diameter of the gudgeon in inches. 7th the weight of wheel in tons and hundred-weights. 8th the diameter in inches, derived from Mr. Tredgold's rule, for the case of greatest wear; the length of the gudgeon being assumed equal to the diameter, which is the usual proportion in practice. 9th is the same, calculated for the ease of ordinary wear. 10th is the diameter of the gudgeon in inches, derived from the practical rule mentioned above, being the cube root of column 7, in hundred-weights.

Table of Gudgeons of Water Wheels.

Manufactures.

Table of gudgeons.

Machinery.

Number.	Material.	Diameter of wheel in feet.	Width of wheel in feet.	Description.	Diameter of cast-iron gudgeons in inches.	Weight of wheels in Tons and Cwts.	Diameter calculated by Mr. Tredgold's rule for great wear.	Diameter calculated by Mr. Tredgold's rule for little wear.	Cube root of weight in pounds.	Remarks.
1	Wood.	25	12	Overshot.	7	Tons. Cwts. 23 14	8.35	7.45	7.79	
2	Cast iron.	16	6	Ditto.	7	12 0	6.64	5.94	6.21	
3	Cast iron.	16	8	Ditto.	6½	16 10	7.26	6.48	*6.91	
4	Cast iron.	32	4½	Ditto.	....	24 0	....	....	7.82	
5	Wheel and buckets.	32	4½	Ditto.	9	20 0	....	....	7.36	
6	Wood.	16	9	Ditto.	6	10 11	6.06	5.40	5.95	
7	Wood.	12½	7	Ditto.	6	5 14	5.16	4.61	4.84	
8	Wood.	32	11	Ditto.	10					
9	Wood.	21	10	Ditto.	7					
10	Wood.	28	6	Ditto.	8					
11	Wood.	18	10	Ditto.	10					
12	Fir.									

The water wheels in the Table were all in the middle of their respective shafts; both gudgeons of each wheel had therefore equal stress.

Remarks on the Table.

(57.) It will be observed by examining the numbers in the above Table, which are all cases of water wheels, that the diameter of gudgeons, computed according to the preceding rule for extraordinary wear, exceeds the diameter determined by taking the cube root of the weight in hundred-weights, and also those in actual service, at least with only one or two exceptions; but for the case of less wear the diameters are smaller, the cube root of the weight in hundred-weights forming a sort of mean between the two, and as the stress, wear, &c. of water-wheel gudgeons are not exposed to such evils, as to consider them of the first class, although perhaps they may exceed the other, the simple practical rule given by Buchanan may be considered well adapted to that particular nature of service.

In the above investigation our attention has been confined to the case of cast-iron gudgeons, which are generally preferred in consequence of their being cheaper and more conveniently formed than wrought-iron ones. Still, however, there are many cases in which wrought-iron gudgeons are employed, and considered preferable. In these, of course, the diameters may be made smaller than in the preceding Table. The relative resistance of wrought and cast iron are to each other as 14 to 9 where the permanent change is considered; and as the resistance to this change is also as the cubes of the diameters, it follows, that where the same resistance is required, the diameters in the two cases may be made inversely as the cube roots of these numbers, or as $\sqrt[3]{9} : \sqrt[3]{14}$, or as .87 to 1. Therefore to find the diameter of a wrought-iron gudgeon we have only to find first that of a cast-iron gudgeon, and multiply that diameter by .87.

Plumber blocks and steps.

(58.) *Plumber blocks and steps*, as we have before defined, are those parts of Machinery which support the pillows, or bearing upon which the pivots and gudgeons of shafts immediately revolve. The pillows, or as they are improperly termed by millwrights *brasses*, are usually made of a composition of copper and tin, very much resembling gun metal, which is much harder and much more durable than common brass, and is found to work with wrought and cast iron with very little friction. (See Art. 20.) Other substances which are cheaper are occasionally made use of, and have in many instances been found equal, at least in durability. At the cotton works of Deanston, near Down, a water wheel has been run-

ning nearly thirty years on pillows of cast iron, with little sensible wear on the gudgeons; nor were they ever liable to heat, which is a good test of the absence of friction. The outer surface of cast iron, particularly when cast in a metallic mould, is remarkably hard, which renders it very durable, at the same time if it be polished to a good surface it will work with little friction. Such pillows, it has been said, are best applied to wrought-iron gudgeons or pivots, but this seems at variance with Mr. Rennie's experiments. (Art. 19.)

Wooden pillows are sometimes employed. Box tree and lignum vitæ were long in use; the latter has however been found an improper substance for the purpose; beech is preferable to either, and has been used with great success for steps, for which purpose also holly has been found to answer very well.

Fig. 11 is a representation of a plumber block, showing the manner in which the pillows are fixed in their supports. *aa* is a cast-iron plate, which is secured by two or more bolts, *bb*, down to the timber or framing of the mill; upon this plate are cast two pillars or supports, *cc*, between which a piece of brass, *l*, is bedded, and has a semicircular notch in it, in which the gudgeon or pivot of the shaft revolves. Another similar piece of brass is fixed into the cast-iron cap piece, *dd*, which is fitted into the space between the two pieces *cc*, and is drawn down firmly upon the gudgeon by the nuts upon the two bolts *ee*. The brasses are prevented from getting out sideways by small fillets projecting from the middle of them, which are received into proper grooves in the cast-iron work. In the same way the cap *dd* is fitted between the pieces *cc* with a fillet and groove, so that it cannot deviate sideways, and then the bolts have only to draw the brasses together. Sometimes a bearing of this kind is fitted up so as to be capable of adjustment, in which case an iron plate, *ff*, is bolted down to the framing, and the bearing plate, *aa*, lays upon it, the same bolts, *bb*, passing through both, and also through the framing beneath. The holes through which they pass in the piece *aa* are oblong, to admit the whole plumber block to be moved sideways, which is done by two wedges *gg*, so inserted at the end of the plate *aa*, between it and the pieces *mn*, which are cast upon the lower plate for the purpose, and can by this means be accurately adjusted in a horizontal direction. The plate *aa* can be raised or depressed by

Pl. iii.
Fig. 11.

Manufac-
tures.

the wedges *h h*, upon which it rests, so that by these means the axle may be adjusted in the exact position required, and then all screwed fast by the bolts *b b*.

The best way to make the interior surface of the brasses for a bearing exactly true, is to have them cast solid, that is, the two halves of the brass in one, with a notch which very nearly but not quite separates them. In this state they can be chucked in a lathe, and the inside bored or turned out true; they may then be separated in two halves, and put into their places to which they should have been previously fitted. Sometimes the bearing is all fitted together, and screwed down in its place, and a borer is made use of to bore or broach out the hole for the brasses.

Friction
rollers and
wheels.

(59.) *Friction rollers* are sometimes employed to diminish the quantity of friction in a bearing: but not with much advantage in heavy Machines, because they are liable to get out of order and require very accurate workmanship. Their effect depends upon converting a sliding into a rolling motion, with only the friction or sliding of the small axis which retains the roller in its place. Friction wheels are also used for the same purpose: they differ from the rollers in this, that the stress is born by the axles of the friction wheels, and by the surfaces of the rollers. The manner of constructing friction wheels is shown in fig. 12 and 13: *a a* is an iron plate which is bolted down upon the framing; it has holes in it to receive the friction wheels *b b*, and has supports cast upon it which are provided with sockets for brasses, in which the pivots of the friction wheels revolve. The friction wheels being fixed in their places, the gudgeon *c* of the shaft lies between them, so that when it turns round it rolls upon them, or rather their circumferences move with it, and, consequently, the pivots of the friction wheels move so slowly as to diminish the friction materially, the proportion depending upon the relation between the diameter of the wheels and the gudgeon.

Fig. 12, 13.

These are, however, much inferior to the friction rollers, if the latter are executed with any degree of accuracy. Plate. iii. fig. 14, is a representation of a set of friction rollers. Here *a a* is an iron plate bolted down to the framing, upon which are cast circular rings *b b*, the interior surface of the ring is turned in a lathe with the greatest accuracy, and the pivot or gudgeon *e*, which is also turned true, rests in its centre, being supported by six rollers, *c c c*, &c. arranged at equal distances of such diameter as to exactly fill up the space all round between the gudgeon and the ring. The rollers, it is evident, must be made all of one exact diameter, and extremely true, and must also completely fill up the space. The gudgeon in revolving has a tendency to turn these rollers, but as they have no fixed centre, they will roll round within the ring in the same direction as the motion of the gudgeon, but very slowly, their velocity being in proportion to the diameters of the gudgeon and the ring *b*. In order to keep the rollers at their relative distances from each other, each one has a groove turned in the middle of its length, as shown in the side figure at *h*, and an iron ring *l*, having six holes or notches in its outer circumference at proper distances for the centre of the rollers, is made to fit upon them. They will, by this means, be kept at their proper distances asunder, and when the gudgeon *c* is introduced between them they will take their proper places and lie truly parallel. It is to be observed, that the notches or holes in the ring *l* do not exactly fit the neck of the

rollers, which have, therefore, considerable play and but little friction; for it is not essential in order to keep the rollers at their relative distances that this ring should be used, except to prevent the danger of their getting displaced by some accident. To prevent dust or dirt getting in, which greatly destroys the action of the rollers, a circular iron plate is fitted into the ring *b* on each side, and secured to it by small screws. One of the circular plates must of course have a hole to admit the gudgeon. These plates are, also, useful in preventing the rollers from shifting their position endways; but to prevent friction, if ever they come in contact, the ends of the rollers should be made a little convex, as shown at *h*, that they may touch at the centre rather than the outsides; they will, however, never bear hard against the plate, having no tendency that way.

Machinery

(60.) A patent was taken out for these friction rollers many years ago, and a large Manufactory was established for making them for various purposes, as carriage and waggon wheels, the gudgeons of water wheels, &c. They were found to possess great advantages, having scarcely any sensible friction when in motion, but were very liable to get out of order, chiefly from the entrance of dust, which occasioned the rollers to wear out of the round more on one side than the other, from inequalities in their hardness, and if once, by any means, the rollers stood still for an instant, the gudgeon wore a flat place in the two rollers beneath it, and they would never run round again; of course, when this effect took place they soon became loose, and presented a greater degree of resistance to the gudgeon than the common brasses. For delicate purposes, where hardened steel can be employed for the rollers and ring, they are still used with advantage, but for ordinary Machinery, the imperfections above described have caused the use of them in most cases to be abandoned.

Patent friction rollers.

For the bearings or steps of vertical shafts, steel is more commonly made use of, as from the great weight they have to support the wear of brasses is very considerable, and requires them to be often replaced, which is generally attended with inconvenience.

(61.) Conical friction rollers are sometimes applied to vertical shafts to diminish the friction. Plate ii. fig. 12 represents a set of rollers for this purpose. *A A* is a plate which supports the weight of the shaft; it has a conical part cast upon it with a hole in its centre, into which is fitted the pivot *B* at the bottom of the shaft. The shaft *D* has a conical plate attached to its lower extremity exactly similar to the conical ridge upon the plate *A A*, and between these two surfaces the friction rollers are situated, which of course bear the whole weight of the shaft, and whatever Machinery is attached to it; the pivot being required simply to keep the shaft in its place. The collars are kept at proper distances asunder by a ring shown separately at *l*, fig. 13. It has three projecting arms, which, being formed into spindles, pass through the centre of the rollers, and the latter secured in their places by collets and cross keys. Now it will be readily seen, that as the shaft revolves the rollers will turn upon the plate *A A*, and thus render the friction much less than in the ordinary kind of bearing. These have, however, the same defects as those attending the friction roller for horizontal shafts already explained, that is, they require exceedingly accurate execution at first, and they have the same tendency to wear out of adjustment, from the entrance of dust, dirt, or other substances and causes not in the power of the

Conical
friction
rollers.
Pl. ii.
Fig. 12.

Fig. 13.

Manufac-
tures.

Framing
mill work.

mechanic to control, so that they are by no means in general use.

(62.) *Framing of mill work* is so varied in its construction, according to the nature and situation of the Machinery it has to support, that a detailed description will be better entered into when necessary under the head of each Machine, and we shall therefore here only speak of the general principles of construction, and describe such parts as are common to all Machinery.

Mill work from its motion occasions a tremour on all parts of its framing which renders it liable to become loose in the joints, and subjects it to a much more speedy derangement than common carpentry. It is besides subjected to violent sudden thrusts from the bad action of wheels, or from reciprocating motions. Wooden framing therefore ought to be made much more strong and stiff than the mere support of the weight would demand, and at the same time sufficiently heavy to give solidity and steadiness; for where the framing of Machinery is not firm and well bound, and a vibratory motion takes place in its parts, such motion expends a considerable portion of the power employed. This loss of power is very difficult of investigation: it is certain, however, that whatever motion of a vibratory nature is communicated by a Machine to the framing and objects in contact with it, must be lost to the effect it would produce were it totally free from such motion. It is to be observed, that light framing made firm and well braced, is preferable to that which is more heavy and not so well connected in its parts; in fact, that stiffness is rather the object to be aimed at than weight, as the heavy framing in its vibration will expend more original power.

Besides strength, stiffness, and solidity, the framing of mill work requires to be constructed so as to be easy of repair, and so contrived that any particular part may be repaired or renewed with the least possible derangement to the other parts of the framing. There is also another consideration which should be attended to, namely, that shafts by the wearing of the gudgeons and the brasses in which they revolve, get out of their true situation, to remedy which the part of the framing which supports them ought to be so constructed as to admit of adjustment. When the motion of the shaft is communicated by the action of toothed wheels a little settling of the shaft from wear, or warping of the framework by putting the wheel more shallow or full in gear, materially affects the action of the Machinery, and in such cases the adjustment of the bearing is a matter of particular consideration. It is found of advantage that the part on which the axle rests should have a small degree of elastic tremour when the Machine is in motion, as such tremour has considerable power in diminishing the friction. It may further be observed, that framing to support Machinery should be as independent of the building as possible, because the tremours it always communicates is exceedingly injurious.

Cast iron possesses great superiority over timber in the construction of framework. It is not only much more durable, but by possessing the advantage of being of uniform texture, and of being cast into any shape, its strength may be beautifully arranged to support the particular kind of stress it has to bear. Timber, on the other hand, being stronger in some directions than in others, and of very limited breadth, is confined in its arrangement, and requires in certain cases much workmanship. See Buchanan on Mill Work.

(63.) *Equalization, Transmission, and Conversion of Motion.*—Although we have hitherto only described the detached part of mill work, and have not at present been able to do much more than give a simple definition of the term Machine, it is necessary to assume that the reader has a more general idea both of the nature and object of a Machine and of Machinery generally when in action, than can be included in a mere definition. It is impossible to carry forward a Treatise on such a subject as the present, with the same precision and order as a Treatise on Geometry, where we proceed from definitions to axioms, from these to theorems, problems, &c., never allowing the employment of a term that has not been already illustrated in some preceding part. In Machinery this cannot be, it is impossible to define and illustrate some of the elementary parts, without a reference to the whole of which that part is only a member, and this must be the case in the present instance in which we are about to speak of Machinery when in motion.

On Equalization of Motion.—The regulators most commonly had recourse to for the equalization of motion may be reduced to the four following: the pendulum, the fly, the fly wheel, and governor, to which, indeed, we may add the air pump.

(64.) *Of the pendulum.*—This regulator is only employed in Machines, where the primary object to be obtained is a uniformity of motion, and its principal use is therefore confined to clocks, or in the form of a spring pendulum to watches and chronometers. It appears from Art. 43. *et seq.* that the resistance which friction opposes to the motion of a Machine is a constant retarding force; and where motion results, it must always be less than the constant motive force; consequently, the difference between the two is the effective, constant, moving, or motive force, and every constant force will produce an accelerated motion; if, therefore, a Machine actuated on by a constant force is put in motion, that motion will be continually accelerated without the employment of some regulator. It has been already observed, that in clocks this is commonly effected by a pendulum, which has a constant tendency to vibrate uniformly; and by means of a part called the escapement, the motive force or weight can only descend a certain portion every vibration; and the time of vibration being from the nature of the pendulum uniform, the motion of the wheels, hands, &c. become uniform also. This subject will be further illustrated in a subsequent Article; it is merely introduced here as being one of the class, and indeed one of the principal regulators of motion.

(65.) *On the fly.*—This consists of four or more radii projecting from a centre, and carrying at their extremities vanes of any convenient size, commonly so fixed that they may be adjusted to any angle; this is then fixed to some revolving part of the Machine, and is made to regulate the motion by the resistance the vanes experience against the atmosphere. This regulator of course ought only to be employed where uniformity of motion is the primary object, because if any force is intended to be transmitted, the motive force will have to overcome the resistance of the fly before it can transmit any further power, and thus an additional and unnecessary quantity of motive power is required. It is not therefore very commonly had recourse to, but it is in a few cases a useful regulator. Such as in the heliostat attached to equatorial telescopes, the common roasting-

Machinery.
Regulators
of motion.

The pendu-
lum.

The fly

Manufactures. jack, the striking part of a clock, and a few other Machines.

Fly wheel and governor. (66.) *Of the fly wheel and governor.*—In all the larger Machines where the primary object is a transmission of force, neither of the two former regulators can be employed, and recourse is then had to the fly wheel and governor; the former being intended to prevent any great and sudden irregularity of motion, by absorbing any additional momentum given to the Machine, which, on the other hand, it yields again when any deficiency of power is experienced on the motive side, or any additional force is to be overcome on the resisting side; while the governor is so contrived that if the acceleration of the Machine increases beyond a certain requisite degree, this acts upon the agent communicating the moving force, and modifies the supply, or otherwise on a different part of the engine to increase the resistance, and thus checks any undue degree of velocity; and, on the contrary, when the velocity is too small, it either acts to increase the supply of motive force or to diminish the resistance, and hence by the combined action of the fly and governor, a steady, uniform motion may be ensured, at least within certain allowable limits.

Causes of irregularity of motion. Several circumstances contribute towards rendering the motion of a Machine unsteady. When the motion depends upon the action of muscular power, whether of men or animals, it is obvious there must necessarily be variability of exertion. If the first mover be the wind, nothing is more proverbially inconstant; if water be the agent, certain irregularities of force and velocity are incident to rivers, and indeed to most supplies of this fluid. In the steam-engine, again, the elastic power of the steam depends upon a proper attention to the fire, to the supply demanded, &c.; the greatest irregularity would therefore ensue, but for the highly ingenious contrivances we are about to describe. Moreover, it is not only irregularity in the power of the first mover that is to be guarded against; a much greater cause for irregularity of motion is found in the variable resistance to which the Machine is exposed. A shaft of an engine is frequently opposed in its different parts to different works, and means will be found described, in the section *Engagement and Disengagement of Machinery*, for throwing these separate works occasionally out of gear, so that one operation may be suspended while the general action of the Machinery is continued. A considerable difference of resistance is thus created, which would greatly interfere with the admirable application of Machinery to the endless variety of uses to which it is now adapted, had not the ingenuity of the mechanic devised a remedy by the simple but admirable contrivances of the fly wheel and governor.

The fly wheel consists of a heavy rim of metal fixed and balanced on its axis, and so connected with the shaft or some other part of the Machinery, as to turn round with it with considerable velocity, but with greater or less according to the nature of the work to be performed by the Engine. The momentum or inertia that may be thus accumulated is so great that it will continue the motion of the Machine for a considerable time when even the whole impelling force is withdrawn, and is therefore admirably calculated to correct the comparatively smaller irregularities to which we have alluded above, not only in the motive power, but also in the resistances to which the Machine is opposed, and such again as arise from the conversion and reciprocation of motion; as also in the temporary application of very great resistances, as in the operation of rolling iron, &c. In the

Machinery. latter case it serves not entirely as a regulator, but rather as an accumulator, for without such a magazine of power as is thus furnished, it would be impossible by the simple power of the Machine itself to produce the requisite degree of force. In fact, it is an indispensable appendage in a very great number of Machines, and it will therefore be necessary that we enter here at some length into its theory, as we have in a previous article into its construction; for it is obvious, that a wheel weighing many tons and of great diameter, viz. from twenty to thirty feet, revolving with considerable velocity, must not only be formed and framed with great regard to strength, but likewise employed with great skill and care, lest the centrifugal force, and consequent strain of the rim on the arms, should exceed that of the cohesion of the parts, and be thus destroyed by its own power. Two instances of this kind have fallen under the observation of the writer of this Essay, one at Merthyr Tydvil, and a second at the King and Queen iron-works, Rotherhithe; in both instances parts of the wheel of several hundred weight were forced through the roofs of the buildings; and in the latter, one fragment, weighing sixteen hundred weight, was projected to a distance of two hundred feet, but fortunately in both cases without producing personal injury.

Theoretical Examination of the Action of the Fly Wheel.

(67.) In order to ascertain the nature and advantages of the operation of the fly wheel, we might separate the question into two cases: 1st, where the motive power is constant, or rather continuous, as in the water or wind-mill; and 2dly, where it is periodic, as in the successive strokes of the piston of a steam-engine. But by making our comparisons rest with the number of revolutions, or number of strokes, and rejecting thereby the slight acceleration which takes place during one revolution or one stroke, that is, conceiving the force to act *per saltum*, we may reduce these two cases into one, and at the same time very much simplify the investigation.

Theory of the fly wheel. Confining ourselves at present to the steam-engine, and disregarding at first the resistance and friction of the parts, considering moreover the fly wheel as attached immediately to the crank shaft, it is obvious that every reciprocating double stroke of the piston will produce one revolution of the fly; if, therefore, l denote the length of the stroke in feet, r the radius of the wheel in feet, and $\pi = 3.1416$, the relative velocity of the circumference of the wheel and piston will be as $\pi r : l$; if also the weight of the wheel, supposing it all collected in the rim, be denoted by w , and the pressure on the piston by p , the relative momenta of the two will be as $\pi r w : p l$. In this state of the question, however, an acceleration would go on indefinitely increasing, not, as in the force of Gravity, at every instant, but at every successive stroke of the piston in the steam-engine, and at every revolution of the shaft in the wind or water-mill, because we suppose no acceleration during the revolution, but a fresh access at every complete rotation. According to this view of the subject, both the velocity of the piston and the circumference of the fly will continue to accelerate, preserving always the same proportion with regard to each other, till the velocity of each is such as is best suited to the power of the engine and to the nature of the work to be performed. After which a resistance being thrown on, equal to the motive power or pressure on the piston, the acceleration will cease, and the

Manufac-
tures.

motion of the engine, while the motive power and the resistance are the same, will continue uniform.

(68.) In order now to ascertain the amount of accumulated power in the circumference of the wheel, we have only to consider the ratio of the two momenta, viz. $lp : \pi r w$, and we shall have for its measure $\frac{\pi r w}{lp}$; that is, a

flow received at the circumference of the wheel would exceed that given by the piston in the ratio of $1 : \frac{\pi r w}{lp}$; but

if a resistance to the motion of the wheel be introduced nearer to the axle of the wheel than at its circumference, the effect of the wheel's momentum will be still further increased, in proportion as the point of application is nearer to the axle; that is, calling that distance d , the

measure of the wheel's effect will be $\frac{\pi r^2 w}{lp d}$. All other

things being the same, therefore the power of the wheel to overcome a resistance will vary as r^2 ; and if every thing is constant but the weight, its power will be as w .

Hence it has been said, it is preferable to increase the radius, preserving the weight, than to increase the weight, preserving the radius, which is theoretically true, but practically false; for by increasing the radius and preserving the weight, we must reduce the dimensions while we increase the strain upon the arms, so that following such a rule without considering this side of the question, would unquestionably lead to the destruction of the wheel by its own centrifugal power, and probably to the sacrifice of many lives. Such accidents we have seen do sometimes occur, and how many of them may be due to those kind of theoretical doctrines which are only true on paper, it is impossible to say. It is perhaps quite within the reach of Mathematical rules, supposing the weight and velocity of the wheel to be given, to compute the requisite dimensions of the arms; but practical men at the present day will find a much better guide in studying those engines of the best performance, which are generally the result of numerous practical deductions, and frequently of dear-bought experience.

To estimate the reduction of velocity in the fly wheel, and consequently in the Machine, from either a temporary suspension of the motive power, or the introduction of a temporary increased resistance, we must consider the ratio between the two momenta. Suppose, for example, $lp : \pi w r : 1 : n$, and the piston or the crank by which it acts, ceased its operation for one stroke, i. e. the down or up stroke, then it is obvious, a momentum equivalent to 1 would be absorbed by the resistance to which the Machinery is opposed, and the velocity of the wheel reduced in the ratio of $1 : \frac{n-1}{n}$,

or as $1 : \frac{\pi w r}{lp} - 1$, or as $1 : \frac{\pi w r - lp}{\pi w r}$; and if instead of the suspension of action being during a stroke, it is only during a small part of it, as actually happens every individual stroke, and supposing this suspension to occupy only the $\frac{1}{q}$ part of time in which the stroke is made, then the change in the velocity of the wheel will be as $1 : \frac{qn-1}{qn}$, which will be nearly inappreciable when the product rw is of any considerable magnitude. It is not so easy to estimate the check given to the

velocity by the introduction of a temporary resistance, it being impossible in many cases to form any idea of its amount; as, for instance, the resistance produced in a rolling mill by the introduction of the iron, and in many other cases. Here, therefore, we can be guided only by practical experience. But when the resistance is of such a nature that a momentum equal to it can be expressed, the reduction of velocity may be computed on similar principles to those of the suspension of action in the motive power, that resistance as transferred to the piston being in effect equivalent to such suspension.

At present the fly wheel has been considered as attached to the crank shaft for the sake of simplifying the illustration of its action, but it is obviously the same in principle, although different in amount, when it is attached to any other part of the Machinery. We have, therefore, only to determine the relative velocity of the piston and the rim of the fly, to multiply the one by the pressure on the piston, and the other by the weight of the wheel, which will give the relative momenta, and hence the computation may be made as above directed. Suppose, for example, the piston of a steam-engine to move with a velocity of $3\frac{2}{3}$ feet per second, and the velocity of the rim of the wheel at 8 feet per second, the pressure on the piston to be 3000 pounds, and the weight of the wheel 10 tons, or 22,400 pounds, and that the piston is ineffectual during one-tenth of the stroke, required the consequent change in the revolution of the wheel.

According to what is above stated, we have for the ratio of the momenta $1 : \frac{22400 \times 8}{3000 \times 3\frac{2}{3}} : 1 : \frac{1792}{110}$ or $1 :$

16.3 nearly, and since $q = .1$, we have $\frac{16.3-1}{1} = 16.2$,

that is, the irregularity of motion will be 162 to 163.

(69.) In the foregoing remarks we have alluded to the question whether it be better to enlarge the radius and preserve the weight, or to enlarge the weight and preserve the radius, when it is wished to increase the momentum of the wheel. We have seen, however, that a certain limit cannot be safely exceeded in the first case, from the tendency that would be brought on to fracture the arms, and even the rim itself, by the increased velocity; and, on the other hand, by increasing the weight and retaining the radius, we should bring a greater strain on the axle, and an additional quantity of friction, so that neither the one nor the other would be had recourse to by the well-instructed engineer, who would doubtless think it preferable to increase both the weight and radius, and by this means give additional strength to resist the additional velocity.

There is also another way in which the momentum may be increased, which is by giving an additional angular velocity to the wheel, but here again we are limited by considerations of strength; for a wheel which has only the proper dimensions for a velocity v , might be destroyed if we gave it a velocity $2v$, so that we are not enabled to proceed on this principle *ad libitum*; and unfortunately it is useless to attempt to give theoretical rules for circumscribing the limits; practical results are the best guides; it may be humiliating to the Mathematician to be told, that his comprehensive science will not reach such questions, but it is not the less true.

We have thus three different ways of producing the same momentum; that is, denoting the angular velocity of a wheel by n , its weight by w , and its radius by r , the momentum is proportional to nwr , each of which quan-

Machinery.

Manufactures. tities may be taken at pleasure within practicable limits. In some instances where the opportunity has offered, experiments have been made to ascertain, in cases where the numerical expression for the momentum is the same, which of two different wheels was preferable. An instance of this kind occurred in His Majesty's Dock-yard at Portsmouth, where there were two wheels of the same weight, but of different radii, the angular velocity of the two being however so proportioned that their momenta were the same, and the result was, that one wheel answered better than the other for one species of work, and the contrary in a different kind of work. In fact, although numerically expressed the same, there is a difference in the two cases, in what may be denominated intensity of action, which is beyond the reach of numerical expression; and hence the inefficiency of Mathematical investigation in this and some other questions of great practical importance.

Governors. (70.) *Of governors.*—We have above described the important services performed by the fly wheel as a regulator of the velocity of mill work, and its action as a corrective of the irregularities to which Machinery is subject. Its effect is, as we have seen, that of a reservoir of power, so that any sudden increase or decrease of the work to be performed, or, what is nearly the same thing, any sudden increase or decrease of the motive power, when of short duration, but little affects the velocity of a Machine: if, however, these changes exist for any length of time, the fly wheel loses its effect, and the Machinery acquires an accelerated or retarded velocity. In order to obtain a perfect uniformity under these circumstances, it was necessary that the velocity of the Machine should govern the supply of motive power, and the means of accomplishing this is admirably attained in the beautiful contrivance termed the governor, which consists of one or more balls revolving with the Machine, and by the action of the centrifugal force moving into different positions at different velocities, and the motion thus obtained is conveyed by a system of Machinery so as to act on the supply of motive power, or on the amount of resistance.

Plate iv. This regulator acting on the latter principle was applied many years ago to wind-mills, in a contrivance called the *lift tenter*, which was employed to correct the effect of the irregular action of the wind, in forcing the corn rapidly through the mill without being sufficiently ground. This Machine, with part of the stone framing with which it is connected, is represented in plate iv. fig. 1. To the stone spindle there are fixed four arms, *a a a a*, and to the hollow cylinder *c*, which is loose on the spindle, are attached four similar arms, *b b b b*; the pendulums, *d d d d*, are suspended from the arms *a a a a*, and have holes near their lower extremities, through which the arms of the loose cylinder pass. When the mill is at rest, these pendulums hang vertically; but when in motion by their centrifugal force they assume an oblique position, and that obliquity is increased in proportion to the velocity, and proportionably raises the loose cylinder *c*. This acts upon one end of a lever, which is connected with the clove upon which the bridge of the stone spindle rests, and accordingly depresses the upper mill-stone as the wind is strong, so that the corn is in all cases sufficiently ground, and at the same time greater resistance being produced to the motion of the stones, the velocity of the mill is also in a great measure regulated.

The most simple form of the modern governor is

shown in fig. 2. *A A* is the vertical axis, which is constantly revolving by the Machinery: at *a* two arms or pendulums are jointed, each carrying at its extremity a heavy metal ball, *b*; from the pendulums proceed two chains or iron rods, *d d*, which suspend a collar, *e*. This slides freely up and down the axle, and has a groove formed all round it, in which the end of a fork *D* is received; and thus the rising and falling of the collar produces a corresponding motion of the end of the lever *D*, which acting through other levers, according to the nature of Machine, regulates the supply of motive agency, whether steam or water.

Machinery.
Fig. 2.

On the Transmission and Conversion of Motion.

(71.) Referring to what has been already described relative to the operation of first movers, it will appear that their effort is always rectilinear, but when they act tangentially on the circumference of a circle, their immediate effect is to produce rotary motion, and in the application of the forces thus obtained, it becomes necessary to transmit the action of what may be called the second mover, to other parts of the Machine; in the course of which rectilinear motion is sometimes required to produce another rectilinear motion, in the same or in a different direction, and with the same or with an increased or diminished speed. In like manner one rotary motion is sometimes made to produce another rotary motion, either in the same or in a contrary direction, and with increased or diminished speed. In other cases rectilinear motion is made to produce circular motion, and circular motion rectilinear; reciprocating motions, both rectilinear and circular, are made to produce continuous motion, and continuous motion reciprocating, &c.

To describe the different ways by which these various effects are produced, would be to analyze nearly every species of Machine that has ever been invented, and would be inappropriate in this place. Our object here is merely to illustrate the more simple means which are had recourse to in connecting the first with the second mover of a Machine at the impelled point, and the last action upon the working point. For the rest, it is conceived that the great variety of contrivances by which the direction of motion is changed in the processes of a Manufactory, in fact all the minutiae of those operations, which the ingenuity of the mechanist has devised for particular purposes, will be best explained individually as they occur in the description of the several engines and processes which it will be our business to illustrate in a subsequent part of this Treatise.

The conversion of rectilinear motion from one direction to another, either with increased or diminished velocity, is generally effected by means of pulleys and blocks, and is too obvious to require any description.

Continuous rectilinear motion is converted into circular motion by means of a descending weight attached to a cord wound about a barrel or axle, as in the case of clocks; the action of the wind on the sails of a wind-mill, and the action of water on the floats of an under-shot wheel, are other instances of this kind which require no particular illustration in this place.

(72.) *To convert a reciprocating rectilinear motion into a continuous circular motion.*—This is a question of great importance in practical Mechanics, and was one of the difficulties which Watt encountered in the early progress of his important improvements in the steam-engine. It is now commonly effected by means of a crank, but

Manufactures.

Action of the crank.
Fig. 3.

other methods are employed for the purpose as described below.

(73.) *Of the crank.*—Let it be required to give a rotary motion to the wheel A B C D, (fig. 3,) about its centre O, by means of a reciprocating, vertical motion of the end of the rod Q F. Conceive the vertical rod Q F to turn freely on a pin at its upper end, and also at F, in any part of the wheel A B C D, or attached to a crank as in the figure, so as to have a perfectly free motion at each end. Then it is obvious that while the point Q ascends, it will pull on the lever F O, till the point F is vertical, and thus produce a motion in the wheel; at that instant the rod Q F begins to descend, and pushes the lever or crank, till it is again vertical below at E; when the rod Q F begins again to ascend, and again drags the lever with it, and by this means gives continued rotation to the wheel. At the two vertical points, E and G, it is obvious that the rod Q F has no mechanical effect, but the inertia of the wheel acquired by its previous motion carries it over these dead points, and the rotation becomes continuous.

It is obvious that the action is different in different parts of the circumference, and consequently that the wheel is unequally urged forward, and hence the important service of the fly wheel described in article (67.) which serves to equalize all these irregularities.

Fig. 4.

In order to investigate the action exerted tangentially on the wheel in any part of its rotation, let C B, fig. 4, represent the vertical line on which the lever acts, and D the position of the crank in any part of its rotation: let also α represent the angle D C O, that is, the angle of the rod's inclination when the crank is at D; let also c denote the angle D O E of position of the crank, and P the vertical power of the rod. Resolve P into the two forces C D, D G, the former being $C D = P \sec \alpha$. Draw D F perpendicular to D O, and let fall C F per-

pendicular to D F, then will F D represent the tangential force at D. Machinery.

Since C F and D O are parallel $D C F = (\alpha + c)$ and we have

$$\text{force in D F} = P \sec \alpha \cdot \sin (\alpha + c)$$

$$\text{or force in D F} = P (\sin \alpha \cdot \cos c + \sin c \cos \alpha) \sec \alpha.$$

In order to exterminate the sine and cosine of the angle α , let the length of the rod C D be to the radius O D as $n : 1$. Then D G being common to both triangles,

$$\sin c = n \sin \alpha \text{ or } \sin \alpha = \frac{\sin c}{n} \text{ and } \cos \alpha =$$

$$\sqrt{\left(1 - \frac{\sin^2 c}{n^2}\right)} = \frac{\sqrt{(n^2 - \sin^2 c)}}{n}.$$

These substitutions being made, we get the force in D F

$$= P \sin c \left\{ \frac{\cos c}{\sqrt{n^2 - \sin^2 c}} + 1 \right\} \text{ which is of course easily}$$

converted into numbers.

And in a similar way we find the additional strain on the axis of the shaft, and consequently the friction to be as

$$P \left\{ \cos c \mp \frac{\sin^2 c}{\sqrt{(n^2 - \sin^2 c)}} \right\}$$

the lower sign being used after the rod becomes a tangent to the circle, that is, when C F falls on the other side of C D, and the upper sign for the position shown in the figure.

The following Table has been computed by Mr. Tredgold, showing the variable power of the crank in different parts of its rotation. The length of the crank is considered 1, and the length of the rod is taken 2, 3, 4, &c. to 7, and the forces in the tangent computed for each case at different angles varying from 0° to 180° .

TABLE.—Showing the variation in the force of the Crank from the formula $\text{Force} = P \sin c \left(\frac{\cos c}{n^2 - \sin^2 c} + 1 \right)$; P being considered as unity.

Portion of the stroke described, the whole being unity.	Number of degrees described by the crank from the top.	Length of connecting rod l in terms of length of crank r .						Stress on the axis when $l = 6 r$.
		$l = 2 r$.	$l = 3 r$.	$l = 4 r$.	$l = 5 r$.	$l = 6 r$.	$l = 7 r$.	
0	0°	0	0	0	0	0	0	1.00
0.067	30	.72	.65	.61	.59	.57	.56	.825
0.146	45	.97	.87	.83	.80	.78	.77	.624
0.250	60	1.10	1.01	.98	.95	.94	.93	.375
0.500	90	1.00	1.00	1.00	1.00	1.00	1.00	.169
0.750	120	.62	.75	.75	.78	.79	.80	.625
0.854	135	.43	.57	.57	.60	.62	.63	.790
0.933	150	.27	.39	.39	.42	.43	.44	.907
1.000	180	0	0	0	0	0	0	1.00

Men at a windlass.

(74.) The action of a man at a windlass is somewhat similar to the above. The great effort of a man in such case is in pulling and pushing, and may be in some measure assimilated to the pulling and pushing power of the rod in the above example. Commonly when men are thus employed a double crank is used, and these are generally placed diametrically opposite to each other; but as this brings the weak point of both cranks on at the same time, they have been sometimes placed at right angles with each other. But not being commonly adopted, we may conclude that practice has decided in

favour of the former position. The best length of crank for men is considered to be about 16 inches.

(75.) Another method of converting a reciprocating vertical or rectilinear motion into a rotary motion is shown in fig. 5; this is called the *sun and planet wheel*. Here a toothed wheel, A, is fixed centrally with the large wheel to which the rotary motion is to be conveyed; B is another toothed wheel, fixed firmly to the end of a vertical rod, C C, so as not to be allowed to turn; and a strong link connects the centres of the two wheels in order to prevent their separating. If now we conceive Sun and planet wheel.

Manufactures. the shaft D to be turned round in the direction of the arrows, it is plain that the wheel B will revolve round the wheel A in the same direction, and thereby elevate the rod CC, till the wheel B is found at the top of the wheel A; when by continuing the motion of the large wheel, the wheel B must necessarily descend to its first position, and so on continually. This, however, as we have stated it, is converting a rotary into a vertical motion; which was done, because in this form its action appears to be more easy to comprehend. We have only now, however, to consider the rod CC to be first put into motion, when it necessarily follows that it must by its action give rotation to the wheel A, and to the large wheel to which it is fixed.

It was by this means Mr. Watt converted the reciprocating motion of his first steam-engines into a rotary motion, not however entirely as a matter of choice; he would have preferred the crank, but was prevented using it by a patent which had been taken out by another Engineer. There are cases, however, in which it may be still used with advantage, although the crank has now entirely superseded the use of it in steam-engines.

Rotary motion is transmitted and converted into rotary motion in the same or other direction in a great many ways, viz. by bands, straps, wheel and pinion, bevel gear, and with various changes of speed; but these are generally so simple and so common as to be familiar to every one, we shall therefore only select one or two cases, and those only where change of direction or change of speed make them rather peculiar.

(76.) *By bands or straps.*—One obvious, and perhaps the earliest method of transmitting rotary motion, with or without a change of speed, is by bands or straps, of which we have numerous common examples. Fig. 6 shows a motion of this kind, in which by having a series of pulleys, or of grooves, in one common pulley, corresponding with others in another such wheel, so as to preserve always the same length of band, a great variety of speed may be obtained by merely shifting the band from one pair of opposite grooves to another opposite pair.

The bevel gear furnishes a method of changing the direction of motion from one line to another, forming any angle with it. See what has already been said on this head, section (33.); see also fig. 2.

(77.) *Alternate cones* are sometimes used for changing the velocity of motion, when this requires to be gradually and uniformly accelerated. Here one of the cones, A, (fig. 7,) gives motion to the other by a belt, which is carried along by a guide, by which means the motion is accelerated or retarded at pleasure, or retained constant while the guide remains stationary.

Another method of changing velocity is shown in fig. 8. The two wheels A and B are fixed on the same axis, a little apart from each other; the other two wheels, C, D, are cast together, and run on an axis with the means of slipping them a little backward and forward; when C D is thrown back on its axis, the teeth of the wheel C engages those of the wheel A, while those of B are thrown beyond the wheel D, and a certain speed is the result of this action; but by sliding the wheel C forward, the teeth of the wheel B engage those of D, and a different velocity results, as is evident.

(78.) The conversion of continuous rotary motion into a reciprocating rectilinear motion, may obviously be effected by merely inverting the methods already described for converting a reciprocating rectilinear motion

into a continuous rotary one, but they are not commonly employed in practice. The two following have, however, been occasionally used for either purpose, accordingly as circumstances required. We shall here speak of them as a means of converting a rotary into a rectilinear reciprocating motion.

Conceive a pinion A, fig. 9, to be made to give motion to the wheel B B', and this again to give motion to the equal wheel C C'; to the axles of these, beyond the beam LL, are fixed the cranks D D', and to pins at their extremities are the suspended rods G G' perfectly free to move. These are fixed to the transverse bar H H, from the centre of which proceeds the rod I to which the vertical motion is to be given. Here it is obvious, that when the pinion A is put in rotation in the direction of the arrow, the motion of the two wheels, and of the cranks D D', will have the directions shown by the arrows between B and C, which will bring the ends D D' of the arms towards B and C, and then towards B' C', and thus by the alternate closing and opening of the two points D D', as well as by their actually ascending and descending, a perfectly rectilinear motion will be given to the rod I.

(79.) *Another Method.*—Conceive the wheel A B, fig. 10, cut with interior teeth to be fixed in its place, within which the interior wheel C D, with exterior teeth, and of half the dimensions of the fixed wheel, is made to revolve. Let a pin truly turned project from its rim exactly opposite its extreme circumference. Then shall this point, by the revolving of the small wheel, ascend and descend vertically in the diameter of the larger wheel, and, consequently, will give to any rod which is attached to it the same vertical or rectilinear motion. The result of this operation is not so obvious as in the former case; it may not, therefore, be amiss to give the reader a geometrical demonstration of the truth of the proposition. This may be done very simply as follows.

Let $aedf$ (fig. 10) represent the fixed wheel, and $ac, b'c$, the interior revolving wheel in two positions, being in the former at the extremity of the vertical diameter ad of the larger fixed wheel, it is to be demonstrated, that when this wheel comes into any other position $b'c$, the point a in its circumference will always be found in the diameter ad . Now to prove this, all that is necessary is to show, that the arc $b'a'$, in the second position intercepted between b' and the vertical ad , is always equal to the arc $b'a$ of the greater circle. Take oo' the centres of the circle in its two positions, join $b'c$, $bo'a'o'$, then it is obvious, that $ba = b'a'$, and that the angle $boa = \text{angle } b'o'a' = 2b'ca$, because an angle at the centre is double the angle at the circumference; but the length of circular arcs are as the angles they subtend multiplied by their radii. Hence the angle of the larger circumference being half that of the smaller, but its radius double the radius of the smaller, the arcs themselves are equal, that is, in all positions $b'a' = ba$, consequently, the point a is always found in the vertical ad .

OF THE FORM AND CONSTRUCTION OF MILLS.

(80.) In the preceding chapter the principles of constructing the different parts of mill work have been illustrated; it remains for us in this to show these elementary parts combined into the form of the mill itself, that is, we have now to explain the manner in which different powers are enabled to give rotation, and to act upon

Machinery

Fig. 6.

Fig. 7.

Fig. 8.

Manufac-
tures.
Construction of
mills.

the impelled point of an engine but at present, without inquiring into the nature of the engine itself, or of the work it is intended to perform. A wind-mill, for example, is the same in its principle whether it is intended to pump water or grind corn, so likewise a water-mill may be converted to the purposes of boring, sawing, rolling, grinding, &c.; a horse-mill, also, as far as its power extends, may be employed for any of the above purposes; and so, also, may the steam-engine. It will, therefore, be understood, that the term mill, as used in this chapter, implies only such a form of Machinery, as will enable the five principal classes of first movers to produce rotation; this rotation once produced, it may be applied of course to the impelling of any engine, or to any manufacturing processes to which its power is competent.

Under this arrangement we have to describe the hand-mill, tread-mill, horse and cattle-mill, wind-mill, and water-mill; and the

Steam-engine, which is also but a mill, according to this acceptance of the term, will be treated of in the following chapter.

(81.) *Hand-mill*.—It is probable that this is a Machine of the highest antiquity. We can scarcely conceive a state of civilized society in which some process was not had recourse to, to prepare corn for the formation of bread, and there can be little doubt, whatever may have been the date of the invention of horse-mills, or of wind and water-mills, that they were preceded by hand-mills. When the World was but thinly peopled, and every family formed almost a distinct community, there was no call for a greater power than what might be furnished by one or two persons working at a mill; and, accordingly, this seems to have been the means adopted even so late as the time of Christ, who says, *Matthew*, ch. xxiv. ver. 41. "Two women shall be grinding at the mill, the one shall be taken and the other left." As population and civilization proceeded, and the advantage of division of labour began to be in some measure understood, it was found desirable that the reduction of corn to flour, (which was doubtless the first intention of the mill,) should be attended to by certain persons for a general supply to the community, and then horse-mills, or cattle-mills, were constructed; and even to this day in the East, mills of this description are nearly the only ones employed. A recent fire at Constantinople which destroyed more than 1500 houses, burned down also 120 horse-mills; a proof of the very little advance which has to this day been made in the progress of the Arts in that ill-fated Country. The water-mill is supposed to be of Greek invention, but the inventors of that useful Machine, the wind-mill, are not known. Wind-mills are, by Montucla, supposed to have been used by the Dutch in the VIIIth or IXth Century, but others have imagined that the idea of their construction was derived from Asia in or about the XIIth Century.

Our business, at present, is to describe the hand-mill, which although wholly superseded in its application to grinding flour, except in very particular cases, is still useful for some purposes where great power or great supply is not wanted, as for grinding malt in families, and for some other domestic purposes. It has been also till lately, and is perhaps at present, employed in some prisons for furnishing a means of prison labour; these, however, are now greatly if not entirely superseded by the much more convenient and appropriate engine the tread-mill.

Various forms of hand-mills have been devised, of which a remarkable one is described in Gregory's *Mechanics*; in which the crank is worked by a rowing motion, the most advantageous way of applying a man's strength. It is an old idea, being described in Bockler's *Theatrum Machinarum*. This contrivance seems only to require a fly wheel to make it a complete Machine.

(82.) A very simple hand-mill is represented in plate v. fig. 1, which requires but little description. *AB* is a strong wooden frame; *W* a face wheel running in proper bearings at *P.P.* This wheel is turned by the winch *E*; the teeth of the wheel *W* engages with the staves of the trundle on lantern *T*, and on the spindle of this is fixed the revolving or upper stone of the mill, not seen in the figure, the stones being enclosed in the case *C*. The corn is first placed in the hopper *H*, whence it passes to the stones, and being ground is carried out at the spout *D*.

Hand-mills are employed in various processes for domestic purposes, and by retail tradesmen for grinding coffee and malt, pulverizing sugar, and for many other uses; but their constructions are generally so simple and so well known, as scarcely to require notice in this place. Some other hand-mills, or Machines of equivalent action, will be explained in subsequent sections in describing different mechanical and manufacturing processes, and in particular we refer to Rustal's hand-mill for grinding and dressing corn, under the section Corn-mill.

(83.) *Tread-mill*.—This is a new and very useful invention, for which we are indebted to Mr. W. Cubit, Civil Engineer. Its utility, however, depends rather upon the purposes to which it is applied than to any intrinsic value it possesses as a mechanical construction. We have seen (§ 12.) that it is impossible to apply human strength as a first mover of Machinery without a great pecuniary sacrifice; consequently, we must not look to the Tread-mill as an economical mode of obtaining mechanical power, as far as expense is considered; but there is a higher order of economy, which is (if we are not much mistaken) administered to by this application, viz. the correction and improvement of the morals of the idle, vicious, and disorderly part of the community. Many of this class of persons are so debased and degraded by the courses of life they have led, that they would prefer, perhaps, the dreary abode of a prison in idleness to that of living by the sweat of their brow, and to such dispositions nothing can act as a better corrective than the Tread-mill. Here they must work, no shifting or contriving will allow them to lie by and throw their share of labour upon their more willing companions in misery; and it is accordingly found by the reports of the Governors of various prisons in which this uncompromising Machine has been erected, that few who have had a full trial of this labour are willing to expose themselves to it a second time. If they must work when in prison, they, of course, had better work out of it, and this appears to have been the actual result in many cases. See *A Report of the Society for the Improvement of Prison Discipline*, 1823.

The usual form of the Machine is a long wheel, varying from eight or ten feet to twenty or more feet in length; and a number of these are sometimes united by couplings to a very great length; the usual diameter is about five feet or about sixteen feet in circumference, furnished with twenty four leaves or steps, each of course of eight inches, and within which, at a sufficient

Machinery.

Simple hand-mill.

Tread-mill.

Manufac-
tures.

depth to leave a foot-hold, it is close boarded, at least in some cases, in others, and those more common, it is left open for the sake of air. Each separate wheel has a bearing at one end or at both, but commonly only at one, the other end being supported by a coupling with the bearing end of the next wheel, and so on, in some large prisons to the number of eight or ten in one continuous line. The number of persons on a wheel depends of course upon its length. In Cold Bath Fields' prison there are eight triple wheels, each three holding thirty or thirty-six persons. In general, between each wheel is a partition reaching above the heads of the prisoners, who are not allowed to hold conversation while at work. The Governor of a prison is thus enabled to keep separate and classify his prisoners, which is a great advantage. When the whole shaft is made into one by couplings, as above described, the velocity of rotation must of course be the same in all; but by means of greater relays in one class than in another, the degree of labour may be modified, or the wheels on which boys and women work may be made of less diameter, and, of course, the rise at each step proportionally less. The common practice is to have the part in front of the wheel boarded up from above its centre, leaving the bottom part open where the steps are successively presented to the unwilling tread of the prisoner; the time on the wheel is usually about half an hour, but each prisoner is relieved singly, and not in a body as formerly.

Description
of a Tread-
mill.

(84.) The construction of this Machine is so simple as scarcely to require a delineation; we have, however, given a perspective view of one, consisting of a triple combination, in fig. 2, plate v. This is shown as elevated about eight or ten feet above the level of the prison yard under a shed. This elevation is recommended for the sake of giving more air to the prisoners when at work; and the part under the floor is convenient for carrying on other prison work, as picking hemp, &c. for prisoners unable to work at the wheel. Each wheel is about eighteen or twenty feet long, and separated from the adjacent one by a space of about two feet. At each end, and between every two wheels, is a short flight of steps, serving for the prisoners to ascend to their work. The wheel being about five feet in diameter, and the lower part a foot above the floor, the centre of the wheel, or treading part, is thus raised three and a half feet. Above the tread part of the wheel, the latter is shut in by boards; rather sloping from the front, and along the whole length, runs a hand rail for the prisoners to steady themselves by while treading.

Arrange-
ment for
conducting
the work.

(85.) The order of working is as follows: each wheel holding ten or twelve prisoners, fifteen or eighteen are made to form one gang, twelve of whom, supposing the larger number, ascend by the steps on the right, and move on, one by one, to the other end, till all twelve are in their places, the other six sitting down in front of the wheel, with their faces towards the yard. The mill is now set in motion by the weight of the persons upon it, and by means of a regulator its speed is made to be about two revolutions per minute. After six revolutions, or three minutes, the man on the left hand of each wheel descends by the left-hand steps, and each man then slips on one place to the left, leaving room for one man on the right, which place is immediately supplied by the right hand man on rest. After another three minutes, or six revolutions, the left-hand man of each wheel descends, the prisoners on the wheel slip on

again one place to the left, the right-hand man on rest ascends, and so on during the whole time of work, the wheel continuing in motion from the beginning to the end of that period.

Machinery.

(86.) By this arrangement every man rests eighteen minutes and works thirty-six; or with ten men on a wheel, each one works half an hour and rests a quarter; but by changing the number of men on rest, or the number on the wheel, the ratio of working time and rest may be varied in any proportion. During all the time of work the most perfect silence is preserved, not only with the men on the wheel, but with those on rest, and thus much of that evil communication which formerly rendered our prisons little better than schools of crime is avoided.

Methods of
regulating
the velocity
of rotation.

In the Cold Bath Fields' prison there are eight triple wheels similar to that shown in the figure, for male prisoners only, which furnish hard labour for about 360 or 380 of this class of persons; and three separate mills, of single and compound wheels, for women. The eight mills in the men's division of the prison are ranged four on each side, in eight distinct yards, along the outside walls, the twelve shafts on each side being united in one long shaft by couplings. The end of each long shaft carries a bevel wheel working in another bevel wheel, on a vertical shaft, by which a vertical revolution is produced. The lower part of this vertical shaft, which descends below the ground level of the yard, works another horizontal shaft, and the motion is thus conveyed to a convenient part of the yard, where it gives motion to the regulator. This regulator consists of a vertical shaft rising about twenty feet above the ground level, and carries at its upper end a horizontal fly, with two arms and a governor. The fly itself is of the kind called the Venetian fly, consisting of a long rectangular frame, with shutters moving like those of the venetian blinds; the position of these blinds or shutters is under the control of the governor, by means of wheel work and levers, so that when the speed exceeds what is above stated, of two revolutions of the Tread-mill per minute, the governor balls fly open, and close the shutters, and by thus increasing the resistance check the velocity; and on the contrary, when the speed is too little the balls fall, the shutters open, the resistance is diminished, and consequently the speed increased.

With a Ve-
netian fly.

(87.) The above method of regulating the velocity of the wheel, however, although very effectual, has been objected to, as it requires a large and unsightly sort of apparatus; Mr. Cubit has therefore invented another method which is not seen outside the prison walls, as the fly generally is. This consists of three, four, or more large blacksmith's bellows, or bellows of that kind, but without valves, so that the receiving and delivering the air is effected at the same aperture or nozzle. One board of these bellows is connected with a crank worked by the mill, and the adjustment for regulating the speed is as follows. The nozzles or openings of the several bellows are brought into one plane in the face of a frame, and a slide with proper openings is made to pass over these apertures, and thereby to open or close them to any extent. This slide is connected with the governor in such a way, that when the speed is too great, the governor balls fly open, and thereby, by means of proper wheel work and levers, close the apertures, and thus increase the resistance to the entrance and expulsion of the air, by which the speed is reduced; and, on the contrary, when the motion is too slow, the governor balls

With air
vessels or
bellows.

Manufac-
tures.

Construc-
tion of the
wheels.

Efficiency
as a mecha-
nical agent.

Remarks
on the ad-
vantage of
the Tread-
mill for
prison dis-
cipline.

close, the aperture is opened, the resistance diminished, and the speed increased. Mr. T. Bramah has given a full description of this apparatus as erected in Huntingdon gaol, with explanatory drawings, in the *Transactions of the Society of Arts* for 1827.

(88.) The construction of the Tread-wheel is exceedingly simple: it consists of one long iron shaft, and three or four (according to its length) cast-iron wheels of about three feet six inches in diameter, with twenty-four spurs or starts, like those of an under-shot water wheel, cast upon them; these starts or spurs are about eight or nine inches in length, and to them are screwed the boards of the same breadth, forming the leaves or steps of the wheel. The cast-iron wheels being first, however, securely fixed at their proper distances on the shaft above-mentioned. In some cases, each wheel has two bearings, but generally, when there are several in the same line, only one, the other end being supported by a proper coupling to the supported end of the adjacent wheel.

(89.) With regard to the efficiency of the Tread-mill as a mechanical agent, we have seen that the whole work at a maximum consists of a man lifting his weight about 12,000 feet per day; and assuming his weight to be 150 pounds, this amounts to only 1,800,000 pounds one foot high per day, or reckoning each man to work eight hours, 225,000 per hour, or 3750 feet per minute, and this is to be understood as the maximum, and as appertaining to the impelled point. Moreover, the prisoners assist themselves greatly by the hand rail, pulling up the body as a person does when ascending a steep staircase; and by so much as the arms assist, just so much is the effective power diminished, so that as a productive mode of employing a man's power, this Machine is entirely worthless, nor could it be made useful by any contrivance. An ingenious person of the name of Hayes sometime back took out a patent for converting the power used on the hand rail into efficient effect, by making these rails act as the steps of an upper wheel; but his invention was but a display of useless ingenuity, and has not, we believe, in any case been adopted.

(90.) As the leading intention of this Essay on Manufactures is to illustrate the nature of the productive Machinery of the Country, it will perhaps scarcely be expected that we should dwell longer on the present subject; but notwithstanding the Tread-mill cannot be classed amongst the productive engines, it is, if viewed in its proper character, a highly useful and simple Machine, at present very imperfectly known to the Public; and the management of it, even by those who have the charge of its working, has not been in all cases judicious.

Previously to the introduction of this Machine, the prisoners in many of our gaols led a life of entire idleness; in others, some works were carried on; and in a few, crank and capstan-mills were employed for breaking, grinding, and dressing corn, beating hemp, and a few other such processes. These, however, were generally ill-constructed, and no rule or uniformity could be observed in affixing a due share of labour to each individual.

These inconveniences, perpetually increasing with the increase of population, and a proportional increase of crime, led to the invention of the Tread-mill, which is perhaps better suited than any other Machine whatever to involuntary labour and prison discipline. Although weight is certainly not an actual and infallible criterion

of strength, it is perhaps the best that can be generally obtained; and as in this Machine the whole labour consists in a person lifting his own weight, the proportional quantity of work performed by each individual approximates nearer to his proportional strength, whether he be willing or unwilling to exert it, than could possibly be effected in any other way.

But while the means are thus afforded of apportioning to every idle individual his proper share of labour, it is important to restrain its use within due limits; when judiciously managed, prisoners have generally benefited in their health, and have left their place of temporary confinement in a better state than they entered it; but if too much is enforced upon them, they will not only be unable to continue the exertion, but injurious effects on their general health may be the consequence. And since in this particular Machine the amount of applied force is not measured, as in many others, at the working point, but at the impelled point, there can never be any necessity for an error of estimation. The amount of applied force is here, as in other cases of animal action, proportional to $t v w$, except that here w is constant, and it is therefore the other part of the product $t v$ which it is the business of those who have the management of these Machines to preserve constant. In general, it is recommended that a number, equal to one-half the number of persons on the wheel, should be relieved at certain intervals, by a relay in waiting of equal amount; so that of the whole number employed two-thirds are working, and one-third resting, the changes taking place successively as above described; but this proportion cannot always be maintained, for want of the usual number of prisoners, and then, of course, for want of sufficient weight, if the mill is performing any certain work, as grinding, dressing, &c., the wheel will move slower. In this case therefore, as the velocity is less the time ought to be greater, in order to preserve the product $t v$ constant; but as the number of working hours are not to be increased, the time must be gained by altering the proportional number forming the relays. For want of proper attention to this point a very unequal degree of labour has been exacted in different prisons, and much credit is due to the Committee of the "Society for the Improvement of Prison Discipline," for the pains they have taken to examine into all these irregularities, and to endeavour, while they are desirous of avoiding excessive labour, to provide means for ensuring such a constant amount of it, as shall be a sufficiently large demand on the muscular powers, to deter the idle and disorderly from paying a second visit to this unaccommodating Machine.

(91.) This Committee, after due examination, states, that 12,000 feet ascent every day ought to form a maximum, and 10,000 feet the minimum of labour; that the best rate is, as nearly as it can be attained in all cases, 48 steps per minute, each step being 8 inches, that is, 32 feet per minute ascent while actually working, and generally the relay of one-third seems best. But when this, for the reason above stated, cannot be, the Committee has, for the convenience of managers, caused to be constructed a sliding scale, very easy to work, by which the proper changes of relays may be immediately settled by the Governor, according to the number of prisoners he may have, whether in excess or in defect of the number for which the wheel was originally intended; they have also had constructed an instrument called a gyrometer for exhibiting the speed of the mill at any time, as also the

Machinery.

Maximum
and mini-
mum of
labour.

Manufactures. mean speed with which the Machine has been worked for any number of hours past. Both these instruments were invented and are sold by Mr. Bate, Instrument Maker, London.

Upon the whole, on a general view of the subject, and considering the great national object intended to be effected by deterring the vicious, while it administers to the improvement of their health and morals, as well as from the actual ingenuity displayed in its construction, our readers will not, we are persuaded, consider these observations inappropriately introduced in this place; and we cannot conclude them better than by giving the following Table of a list of all the mills of this description which were in actual work in our different

prisons in 1823, since which time many more have been erected, and much greater uniformity introduced into their management, both as regards their speed and the actual application of their power.

In this Table are given, first the names of the place and prisons, the number of persons forming the whole complement for which the mill is intended, the number of divisions or separate wheels, the proportion of the persons on the wheel, the velocity of ascent, hours of labour, nature of the work performed, and, in fact, every particular that can be interesting to the curious inquirer and the philanthropist or moralist, anxious for the amelioration of the more vicious classes of the community.

(92.) Table of Treadmill Labour in various Prisons in Great Britain.

Places where erected.	Number of persons on the whole wheel.	Number of separate wheels.	Ratio of No. of persons on the wheel to the whole number.	Proportion of labour.		Number of working hours per day.		Height raised per day.		Nature of the work performed.	Profit.	Proportion of work by different mills, reduced to a mean of 8 hours.
				No. of steps per min.	Height of each step.	Winter.	Summer	Winter.	Summer			
					Inches.	Hours.	Hours.	Feet.	Feet.			
BEDFORD.												
New House of Correction.....	24	3	$\frac{2}{3}$	48	$7\frac{1}{2}$	6	9	7,200	10,800	{ Grinding and dressing } all sorts of corn.	£50 per annum.	9,600
Old House of Correct.	12	2	$\frac{1}{2}$ to $\frac{2}{3}$	40	8	6	10	6,400	10,650		Ditto.	Ditto.	8,500
BERKS.												
Reading County	40	4	$\frac{1}{2}$	48	8	8	10	10,950	13,700	Grinding corn.	.....	10,950
CAMBRIDGE.												
Cambridge County ..	32	2	$\frac{2}{3}$	51	$7\frac{1}{2}$	7	10	8,900	12,700	Ditto.	£123 last year.	10,175
CHESHIRE.												
Knutsford	20	2	$\frac{2}{3}$	48	$8\frac{1}{2}$	..	6	..	8,400	Pumping.	.....	11,200
CORNWALL.												
Bodmin	10	1	$\frac{1}{2}$	44	9	7	10	9,900	7,050	Friction lever.	.....	11,300
DEVON.												
Exeter County	62	4	$\frac{2}{3}$	48	$7\frac{1}{2}$	6	8	7,200	9,600	Grinding corn.	2d. per bushel.	9,600
Exeter City	10	2	$\frac{1}{2}$	52	$7\frac{1}{2}$	7	8	7,000	8,000	Beating hemp.	.....	8,000
DORSET.												
Dorchester	48	3	$\frac{2}{3}$	48	8	7	9	10,080	12,900	Grinding and pumping.	.....	11,500
DURHAM.												
Durham	32	4	$\frac{2}{3}$	58	7	6	8	7,100	12,150	Ditto.	.....	12,150
ESSEX.												
Chelmsford	36	2	$\frac{2}{3}$	40	$7\frac{1}{2}$	7	$9\frac{1}{2}$	7,850	10,650	Ditto.	.....	9,000
GLOUCESTER.												
Gloucester Penitentiary	36	4	$\frac{2}{3}$	48	8	6	9	6,900	10,300	Ditto.	£100 per annum.	9,200
Horsley	11	1	$\frac{1}{2}$	48	7	6	10	6,900	11,500	Ditto.	{ £15. 16s. 11d. in } 9 months.	{ 9,200
HANTS.												
Winchester County..	22	2	$\frac{1}{2}$ to $\frac{2}{3}$	48	8	..	10	..	13,500	Grinding corn.	£100 per annum.	10,800
Newport, I. of Wight	9	1	$\frac{1}{2}$	80	7	8	..	..	8,400	Friction wheel.	.....	8,400
HERTS.												
Hertford	40	4	$\frac{2}{3}$ to $\frac{2}{3}$	48	$7\frac{1}{2}$	7	9	9,450	12,150	Grinding corn.	£158 per ann.	{ 10,800
St. Alban's.....	12	2	$\frac{1}{2}$	50	8	6	8	6,000	8,000	Pumping.	.....	{ 9,600
LANCASHIRE.												
Lancaster Castle....	4	1	$\frac{1}{2}$	60	8	7	10	..	4,000	Ditto.	.....	{ 8,000
LINCOLN.												
Kirton	6	1	$\frac{1}{2}$	52	11	6	6	8,600	8,600	Grinding corn.	.....	{ 9,600
Louth	24	2	$\frac{1}{2}$	48	9	7	10	7,550	10,800	Ditto.	£80. 13s.	{ 8,650
Boston Borough	14	2	$\frac{2}{3}$ }	78 } 40 }	9 }	5 }	.. }	10,500 } 5,400 }	.. }	 }	 }	{ 16,900
MIDDLESEX.												
Cold Bath Fields....	240	8	males $\frac{2}{3}$ fema. $\frac{1}{3}$	44	8	6 $\frac{1}{2}$ }	10	7,600	11,700	{ Turning fly wheel.	 }	{ 9,380
London Bridewell ...	80	12	$\frac{2}{3}$	30	8	7	8	5,700	7,000		Grinding.		.....	{ 7,000
NORFOLK.												
Swaffham	48	4	$\frac{2}{3}$	32	8	$7\frac{1}{2}$	$9\frac{1}{2}$	7,200	9,100	{ Grinding & pumping. }	25 per cent. on the bread made in the pri- son.	{ 7,650
Wymondham	13	1	$\frac{1}{2}$	40	$7\frac{1}{2}$	$7\frac{1}{2}$	10	4,550	6,100				Grinding.	.....	{ 9,700
NORTHUMBERLAND.												
Newcastle	12	2	males $\frac{2}{3}$ fema. $\frac{1}{3}$	87 } 44 }	7 }	5 }	6 }	10,050 } 2,050 }	12,100 }	{ Crushing oats, beans, } &c. }	 }	{ 16,100
NOTTINGHAM.												
Southwell	48	4	$\frac{2}{3}$ }	2wh 48 2wh 36 }	8 }	7 }	8 }	10,050 } 7,550 }	11,500 }	{ Fly regulator.	 }	{ 11,500
												{ 8,650

Table of Treadmill Labour in various Prisons in Great Britain, continued.

Places where erected.	Number of persons on the whole wheel.	Number of separate wheels.	Ratio of No. of persons on the whole wheel to the whole number.	Proportion of labour.		Number of working hours per day.		Height raised per day.		Nature of the work performed.	Profit.	Proportion of work by different mills, reduced to a mean of 8 hours.
				Number of steps per min.	Height of each step.	Winter.	Summer.	Winter.	Summer.			
					Inches.	Hours.	Hours.	Feet.	Feet.			
STAFFORD.												
Stafford	44	2	1	60	7	7	11½	9,800	16,000	Grinding.	{ £88. 11s. in } nine months.	11,200
SUFFOLK.												
Bury	56	4	1	48	7	7	10	7,800	11,150	Grinding and pumping.	£117. 15s.	8,950
Ipswich County	28	4	1	40	7	7	10	6,500	9,300	Ditto.	£82. 19s. 4d.	7,450
SURREY.												
Brixton	126	10	1	48	7½	7	10	9,400	12,500	Ditto.	.....	10,800
Guildford	35	4	1	48	7	7	10	9,400	13,400	.....	.....	10,750
			males fema.					8,800	13,600	.....	.....	10,080
SUSSEX.												
Lewes	18	2	1	44	7½	7	9	5,750	7,400	Grinding.	£35 per annum.	6,600
WARWICKSHIRE.												
Warwick	24	3	1	1st wh. 60 2d wh. 59 3d wh. 55	8½	6	10	10,200 10,000 9,350	.. .. ..	An hydraulic regulator.	.....	{ 13,600 13,300 12,400
YORKSHIRE.												
Wakefield	96	16	1	44	7¾	7½	10	9,500	12,700	Grinding.	£48. 15s. per qr.	10,200
WALES.												
Haverfordwest	10	2	1	48	7½	8	10	7,200	9,000	Grinding.	£45 per annum.	7,200
SCOTLAND.												
Edinburgh Bridewell.	44	7	1	56	7	9	9	..	12,900	Cutting corks.	.....	11,500

Horse and cattle-mills. (93.) *Horse and cattle-mills.*—We have seen (Art. 12.) that the employment of horses as first movers of Machinery is disadvantageous, in comparison with wind, water, or steam, as well in regard to expense as to convenience, in cases where any of them may be employed, and where the number of horses requisite for performing the work is considerable, but there are many kinds of work and manufacturing processes in which the power of one or two horses only is required; and in these perhaps the horse-mill has still an actual advantage over a steam-engine of so small a power, particularly if the work is not constant. As we have not in this place to describe the processes conducted by the power of the horse-mill, but simply to show its mode of action, and the means of obtaining rotation, we shall stand in need of very little illustration. The principal variety in the mode of communicating motion by a mill of this kind is, that in some the large cogged or bevelled wheel, which gives the first action, is placed above the shaft; and in others when the process is carried on below the level of the horse tread, this wheel is placed below; these two cases are shown in plate v. figs. 3, 4, 5, 6, and they constitute, indeed, almost the whole variety, while the processes carried on by the mill are not considered. For agricultural purposes, cattle are sometimes made to work in mills of this description, but not very commonly. In the East, oxen perform a great part of the work of these mills. In Egypt, they are used for drawing water, grinding corn, and in various other cases. In Constantinople, horses are more commonly employed than oxen; but in the Provinces, both Asiatic and European, the latter are the principal agents.

Pl. v.
Fig. 3, 4, 5,
6.

The action of the horse in these Machines being perpetually restrained by the circular path in which he walks, his power is not so great as when drawing in a direct line, but it is difficult to estimate the amount of this disadvantage. One rule, however, laid down by

millwrights, it will always be well to observe, which is, that the diameter of the horse-path ought never to be less than eighteen feet.

(94.) *Wind-mill.*—Wind is the least expensive of our Wind-mill. first movers; its power may also be said to be unlimited; but it is so irregular in its action, and ungovernable in its effects, that there are few uses besides the grinding of corn and pumping of water, that it can be applied to with any advantage.

By the term wind-mill is usually understood a mill for grinding corn; we shall, however, here treat it simply as a first mover of Machinery, describing only such parts as are required to obtain a rotary motion from the force of the wind, which rotary motion once obtained, may be applied to the grinding of corn, pumping or raising of water, or any kind of Machinery where extreme regularity is not essential to its good effect.

The invention of wind-mills is not of very remote date. According to some authors they were first used in France in the VIth Century; while others maintain they were brought to Europe in the time of the Crusades, and that they had long been employed in the East, where the scarcity of water precluded the application of that powerful agent to Machinery. Montucla, in his *Histoire des Mathématiques*, states that there is reason for considering that they were the invention of the VIIIth, IXth, or Xth Centuries. Vitruvius describes the water-mill, but does not mention the wind-mill, which he most probably would have done, if it had been known in his time; and as this latter Machine is known to have existed for some Centuries in Holland, where its use seems almost absolutely necessary, from the vast extent of land, level with the sea, which requires draining, and which of course precluded the use of water-mills; it is not, therefore, unlikely that it had its origin in that Country.

The vertical wind-mill, which is the most simple

Manufac-
tures.

Machine, and that most commonly adopted for applying the power of the wind to obtain a rotary motion, consists of an axle or shaft, placed in the direction of the wind, and usually inclined about ten or eleven degrees from the horizontal line. At the end of this axle four arms are fixed perpendicularly to it, which cross each other at right angles; and into these small cross bars are mortised at right angles, and other bars joined to them parallel to the length of the arms; so that they intersect each other in the manner of lattice-work, and form a surface upon which a cloth can be spread to receive the action of the wind. The planes of these sails are placed obliquely to the plane in which the four arms are situated, so that when the wind blows in the direction of the axle it does not impinge upon them at right angles to their surfaces, but obliquely; hence the effort of the sail to recede from the wind causes it to turn round upon its axle, and a rotary motion is thus produced, which by means of bevelled wheels, or common face wheel and trundle, is communicated to a vertical shaft to which is attached the Machinery to be put in motion.

Pl. vi.
Fig. 1, 2.

As the direction of the wind is perpetually changing, some contrivance is necessary for bringing the wind shaft and sails into their proper position, which is effected in two different ways. In the old mill (plate vi. fig. 1) termed the post-mill, the whole building which contains the Machinery is sustained upon a vertical post, and can be turned upon it by means of a lever. In the more modern wind-mill, (fig. 2,) the wind shaft is situated in a dome or cap, which revolves upon rollers, and can be turned into the direction of the wind, either by hand, or be made to adjust itself by the aid of a vane or rotating fan, situated at the extremity of a long horizontal arm, which lies in the same vertical plane with the wind shaft.

Post-mills.

(95.) *Post wind-mills* are necessarily limited in their size, as the whole building has to be moved for every variation of the wind. Fig. 1 is a section showing the interior of a mill of this description. The mill house is of a rectangular figure, the narrow front being presented to the wind. A B is the wind shaft, one end of which has a bearing on the beam C of the framing of the mill, and the other is supported in a similar way by a beam D; the part of the shaft outside the mill is larger, and made square, and has two square holes or mortises through it into which the whips or arms of the sails are fitted and made fast by wedges, *a a*. The wheel E E, which is termed the brake wheel, is attached to the wind shaft; it has a rim of wood, *b b*, on its circumference termed the brake, one end of which is attached to a fixed part of the mill, and the other, by means of an iron rod, to a lever *c d*, so that by pressing down the end of the lever the brake is made to bind upon the circumference of the wheel, and thereby produces such a resistance that the mill may be at any time stopped. The brake wheel is here represented on the old construction, *i. e.* the face wheel, which is supposed to work a trundle not shown in the figure.

The lower floor of the mill is made to receive the post P upon which the mill is turned round to face the wind. This post is a very strong tree, which is held perpendicularly by fixing it upon the middle of two long timbers which form a large cross upon the ground, and which constitute the base of the whole mill. The post is secured in its vertical position by four oblique braces, F F F F, which extend from the ground cross to the middle of it, leaving ten or twelve feet of the

upper part, which is made round, clear from the obstruction of the braces. This round part of the post rises up through the middle of the lower chamber, in the floor of which a circular collar is formed to the exact diameter of the post. At the upper end of the post is a pivot or gudgeon, which enters into a socket fixed to one of the strongest beams, G, in the middle of the upper floor; this beam must necessarily be very strong, as it has to sustain the whole weight of the erection. In this way the mill is made to turn freely upon the pivot, while the collet in the lower floor serves to keep it steady and in a vertical position. L is a ladder for the purpose of ascending to the mill; it is united by joints to the back part of the framing, and has a rope, M, fastened to the lower end, which passes in an inclined direction into the mill, so that by a lever, or pulleys it can be raised at pleasure clear of the ground. The ladder thus raised serves as a lever for turning the mill round, which is usually done by manual labour; sometimes, however, more force is necessary, and a small capstan is provided to draw a rope attached to the end of the ladder. This capstan is movable, and can be fastened at pleasure to any of the posts which are fixed in the ground for the purpose. When the mill is by these means placed in the desired direction, the ladder is let down to the ground, and its position being on the opposite side to that of the sails, it serves not only for ascent and to keep the mill steady in its position, but acts as a stay to resist the tendency of the wind to overturn it, an occurrence which sometimes happens in mills of this description. Post-mills being limited in size, are also limited in their application to Machinery, and, in England, they are seldom used for any other purpose than that of grinding corn. In Holland there are some made use of upon this principle, where the post upon which the mill turns is made of very large dimensions, and has a hole down the centre of it, through which a perpendicular axle passes to convey the power down to a building below. In this way the mill is applied to saw wood, to make paper, or any other purpose; the construction is, however, more complicated and less effective than the mill termed the smock-mill, where the head, or top, only turns round. This we shall now endeavour to describe.

(96.) *The tower or smock-mill* is the description of Tower or mill most commonly adopted in this Country, it being smock-mill. more convenient in its arrangement, and limited in its extent only by the difficulties attending the construction of sails of large dimensions. The power of wind-mills is of course so variable, according to the velocity of the wind, that it is difficult to make an estimate of it; the larger description of smock-mills are, however, considered to do the average work of six or eight horses. Fig. 2 is a representation of the upper part of a mill of this kind, AA are the sides of the stationary part or body of the mill, which is either built of brick or stone, or framed in timber. CC is a wooden curb attached firmly to the top of the wall, and upon which the rollers of the cap revolve. In brick buildings the fixing of this curb is a matter of some difficulty, as it is of essential importance that it should be perfectly firm and secure, and not liable to get loose from the continual jarring motion of the Machinery. It is commonly secured either to timbers built in the brickwork, or to long iron rods which extend to a considerable distance down the walls. BBB is the cap, or head, of the mill, which is made of timber strongly framed together, with a circular curb at

Fig. 2.

Manufac-
tures.

the lower part which revolves upon the one attached to the body of the mill. S S is the wind shaft, which is here represented of iron, the material now almost universally employed for that purpose: it has two sockets cast in the end outside the mill, into which the whips of the sails can be secured much firmer than in wooden shafts. It has two bearings on the framing, one in front, and the other some distance behind the centre in a similar way to the post-mill. The *pillows* of the bearings of wind shafts are usually made of brass, but sometimes of a peculiar kind of stone, called Nottinghamshire block, which is found to be a material much better suited to the purpose, as it works with little friction, and for a great length of time, which is of course a very important advantage where the replacement is a matter of much difficulty. The driving or brake wheel, D D, is bevelled, and made very commonly with two rows of teeth which act alternately with similar ones upon the bevelled crown wheel N, producing by this means a more regular motion than the common bevelled wheels. This mode of making the teeth is termed by millwrights *hit and miss*; it has already been described under article (27.) In modern mills both the brake and crown wheels are very commonly made of iron, and are attached to their shafts by the usual mode of keying. Sometimes wooden wheels are attached to the iron shafts, in which case arms are cast upon them, to which the wheels are bolted.

Of the
brake.

Fig. 3.

(97.) The brake does not differ much from those used in the post-mill. It consists of a rim of wood which passes nearly round the circumference, one end is attached to some part of the framing, and the other to the lever *b b*, seen in fig. 3. By means of a rope which passes over a pulley to the outside of the mill, a man from below is enabled to raise the end of the lever, and engage it with a hook, which is so constructed, that when the lever is thus raised the brake is clear of the wheel all round, and the mill is perfectly free to move. When it is necessary to stop the mill, the man by pulling the rope disengages the end of the lever from the hook, and allows it to fall by its own weight, which brings the brake down upon the wheel, and causes, by this means, so great a resistance to its motion, that there are very few cases, even in the highest winds, when a mill cannot be thus brought up.

The construction of the brake is a part of mill-making which should engage the particular attention of the workman, as their failure or fracture is often attended with the most serious consequences. In a sudden gale of wind, a mill, if allowed to work, would go at such a velocity, as not only to endanger the breaking of the Machinery but likewise the setting fire to the mill itself: under these circumstances the brake, of course, is the only means of stopping it. We are acquainted with an instance, where the handle of a brake having snapped in a gale of wind, the mill went at such a velocity, that one of the upper stones flew to pieces by the immense centrifugal force, and the miller, who unfortunately happened to be on the same floor, had both his legs taken off by one of the pieces, which afterwards passed through the side of the mill.

Plan of the
cap.

Fig. 4.

(98.) R R, fig. 2, is a ring of rollers which supports the whole weight of the cap, and by means of which it may be turned round upon the curb *cc*, with great facility, in any direction. The rollers *a a a a*, seen in fig. 4, which is a plan of the cap, are for the purpose of keeping it in its place; they are attached to the upper curb, and

revolve against the inner surface of the lower one, which is made very smooth and true; the framing in which these rollers are fixed, ought to be very firmly attached to the upper curb, as it has to withstand the whole force of the wind in its tendency to overturn the cap, an accident which has happened in high winds. By some millwrights rollers are not made use of in either of the above cases, the parts being made simply to slide upon each other; a method which is certainly less liable to get out of order, but it is attended with much more friction, and cannot be made use of for the self-acting caps, which would not have sufficient power to turn the mill under these circumstances.

Several methods are employed for turning the cap in its required direction; in all cases, however, the stationary curb has cogs formed upon its circumference, and an endless screw, or a pinion, which is attached to the cap, works in it. The mode of applying the force of a man to the pinion is shown in fig. 3; an endless rope passes round a wheel *a* and to the bottom of the mill; this has a pinion *b* upon its axle, which engages a toothed wheel on another axle *c*, to which is fixed the pinion required to work in the cogs of the stationary curb. In this way a man outside the mill can turn the cap round with great facility in any direction.

The mill shown in fig. 2 has the self-adjusting cap which is turned round by the force of the wind acting upon the flyer or fan, and is so contrived that it always presents the sails in the proper direction. A small pair of sails, or fans, M, are attached to the projecting framework, L L, of the back part of the cap; it has a pinion upon its axle, which engages in a wheel *b* attached to the inclined axis *cc*, and at the other end of this axle a bevelled pinion is fixed, which works in a wheel *e* on the vertical spindle of the pinion *f*; (see also fig. 4;) this latter pinion engages the cogs on the outside of the rim of the fixed curb, and by these means whenever the fan M is turned, it moves the head of the mill slowly round with a power depending upon the ratio of the radii, or number of teeth in the wheels and pinions above described. It will be readily seen by examining the manner in which the sails of the fan are constructed, that when its plane is in the direction of the wind it will not be put in motion by it, but if the wind varies in the least from the direction of the main shaft of the sails, it acts obliquely upon these vanes or sails of the fan, and turns them round in such a direction that, on whichever side the wind may come, the motion thus conveyed to the Machinery of the cap brings it again into the direction of the wind.

This ingenious contrivance is not a very recent invention; it is made use of in a great many cases, but is considered by some millwrights too slow in its action, as it is sometimes necessary in sudden gales, where there is danger of setting fire to the mill by using the brake, to turn the sails quickly out of the wind; whereas the action of the fan is constantly to bring it in. In this case, the self-acting cap is inconvenient and dangerous; but as these accidents happen but very rarely they ought not to be advanced as a serious objection to this contrivance, which, in other respects, has many advantages.

(99.) *Construction of the sails.*—The construction of the sails, and the method of fixing them to the wind shaft are operations which form the most important branch of mill making, and upon which materially depends the power and good effect of the mill. Cast-iron shafts,

Machinery

Self-adjust-
ing cap.

Construc-
tion of the
sails.

Manufac-
tures.

Fig. 5.

which are now almost universally made use of from the great advantages they possess over wooden ones, have two sockets or rectangular holes in their extremity, for the reception of the arms; and two pieces of timber, (*h h*, fig. 5.) of considerable length, termed the *horns*, are placed at the back of them, to which the arms are secured for several feet of their length by screw bolts and nuts. These horns serve not only to keep the arms steady in the sockets, but very materially to strengthen them, and as an additional security in large mills, braces are sometimes attached to near the end of the arms, and to a projected part of the wind shaft. In some instances cast-iron arms are left on the shaft to secure the whips in the sockets; this method is, however, neither so secure, or so frequently adopted as the former one.

Fig. 6.

Referring to fig. 6, *DEFG* is a section of the shaft perpendicular to the axis *C*. *HH*, *AB*, are the whips which are placed at right angles to each other; they are about 10 inches square, or 10 by 8, and 40 feet long, consisting of one piece of timber; it is, however, sometimes necessary to employ two pieces scarfed together, in which case strengthening pieces are attached, and from these the braces proceed to the projected shaft.

Fig. 7.

At a distance, *CL*, equal to one-seventh of the whip, the first bar, *LM*, is fixed; it is represented in the vertical projection of the sail, fig. 7, by the dotted line *oo'* which makes an angle of 60° with the axis of the wind shaft, and in the same figure the dotted line *oP* is the projection of the outermost bar *NB'*, which makes an angle with the same axis of 80° . The space *LN* is divided into an equal number of parts for the position of the intermediate bars, of which there are usually about twenty. These bars are mortised into the whip, and at the other extremity into the piece *MB'*, which extends the whole length of the sail and serves to secure their ends. It will be seen that each bar makes a different angle with the axis. In this case, the difference of the extreme angles being 20° , and there being twenty bars, the difference of angle in each successive bar is 1° .

All the bars are usually made of the same length, *viz.* about five feet, but in some mills the outermost is made to project about half its length on the other side of the whip, the intermediate ones being gradually diminished to the first bar which does not project; these are termed enlarged sails. In other mills the outermost bars are made of less length to imitate the wings of a bird; these, however, are not considered good.

The square sails now commonly adopted in this Country, are known by the term Dutch sails. They have been minutely described by Coulomb from an examination of more than fifty mills in the neighbourhood of Lisle.

These various Machines he found to perform the same quantity of work when the wind had a velocity of about 18 or 20 feet per second, though some differences existed in the inclination of their axles or wind shafts, and in the disposition of their sails; and from that circumstance Coulomb concluded that the parts of the Machine must have been constructed and disposed so as to produce nearly the maximum effect.

Dutch sails.

(100.) The length of the Dutch sails from their extremity to the centre of the wind shaft is about 33 feet; they

have a rectangular form, and are a little more than six feet wide, five feet of which are covered with the cloth, and the remaining one foot is thin board. The sail cloth commences six feet from the centre, and is, therefore, only 27 feet long. The line of junction of the board and cloth forms on the side which faces the wind a curve sensibly concave, at the commencement of the sail; but the curvature diminishes gradually till it vanishes at its extremity. The angles which the tangents to these curves form with the plane of their motion is called the *angle of weather*. This at the first bar is 30° , and gradually diminishes to 12° in some cases, and to 6° in others, varying within these limits accordingly as the inclination of the wind shaft varies from 8° to 15° .

We have above only considered the sails of wind-mills to consist of four arms; there are, however, some few instances in which five or more are made use of, but such cases are rare, and it will, therefore, not be necessary for us here to enter into a particular description of them.

(101.) *On the best shape and angle of inclination of the sail of wind-mills.*—This is a subject which has engaged the attention of several mathematical and scientific men, and among others the celebrated Smeaton, who, in two papers read before the Royal Society, described the result of a very complete and satisfactory set of experiments made with a view of correcting the anomalies in the results of the mathematical investigations of Parent and Maclaurin. A description of these experiments has been already given in the Essay on PNEUMATICS in this Work, to which, or to the *Philosophical Transactions*, vol. li., we beg to refer the reader for the detail; in the present instance it will be sufficient to give those only which more particularly bear upon the present subject.

The apparatus he made use of consisted of a vertical axle supported so as to be free to revolve in a proper framework, with a long horizontal arm attached to it, at the end of which were fixed four small movable sails. The vertical axle being set in motion by means of a weight attached to a rope wound round its circumference, the sails met with a constant and equable blast of air, and a string, with a scale for weights affixed to it, was attached to the axle of the sails, which served as a measure of their power to revolve, so that by this means a comparison of the powers of different shapes and angles was accurately made. In the following Table are given the results of nineteen sets of experiments on wind-mill sails of various structures, positions, and quantities of surface.

Several experiments were made for each description of sail to ascertain the maximum effect, *i. e.* the greatest product of the weight into the number of revolutions of the sails. In Table I., column 4 is the number of revolutions of the sails unloaded; column 5 the number which produced the maximum; column 6 the weight at the maximum; and column 8 the maximum or greatest product of weight multiplied into the number of turns. The other columns are sufficiently explained by the heads, and need no further remarks.

The velocity given to the centre of the sails in the circumference of their circle was six feet in a second.

In the following results a proper allowance is made for the friction of the pulleys and rigidity of the ropes, both of which were accurately ascertained by Mr. Smeaton.

Machinery.

Mills with
more than
four arms.

Best shape
and angle
of the sail.

TABLE I.—Experiments on Wind-mill Sails of various Constructions, Angles of Inclination, &c.

The description of sails made use of.	Number.	Angles at the extremities.	Greatest angle	Turns of the sails unloaded.	Turns of ditto at the maximum.	Load at the maximum.	Greatest load.	Product.	Quantity of surface.	Ratio of the greatest velocity to the velocity at the maximum.	Ratio of the greatest load to the load at maximum.	Ratio of surface to the product.
Plain sails at an angle of 55°	1°	35°	35°	66	42	7.56	12.59	3.18	4.04	10 : 7	10 : 6	10 : 7.9
Plain sails weathered according to the common practice	2	12	12	..	70	6.3	9.56	4.41	..	..	10 : 8.3	10 : 10.1
	3	15	15	105	69	6.72	8.12	4.64	..	10 : 6.6	10 : 8.3	10 : 10.55
	4	18	18	96	66	7.0	9.81	4.62	..	10 : 7	10 : 7.1	10 : 10.15
Sails weathered according to Maclaurin's theorem	5	9	26½	..	66	7.0	..	4.62	..	..	..	10 : 11.4
	6	12	29½	..	70½	7.35	..	5.18	..	..	..	10 : 12.8
	7	15	32½	..	63½	8.3	..	5.27	..	..	..	10 : 13
Sails weathered in the Dutch manner tried in various positions	8	0	15	120	93	4.75	5.31	4.42	..	10 : 7.7	10 : 8.9	10 : 11
	9	3	18	120	79	7.0	8.12	5.53	..	10 : 6.6	10 : 8.6	10 : 13.7
	10	5	20	..	78	7.5	8.12	5.85	..	..	10 : 9.2	10 : 14.5
	11	7½	22½	113	77	8.3	9.81	6.39	..	10 : 6.8	10 : 8.5	10 : 15.8
	12	10	25	108	73	8.69	10.37	6.34	..	10 : 6.8	10 : 8.4	10 : 15.7
	13	12	27	100	66	8.41	10.94	5.80	..	10 : 6.6	10 : 7.7	10 : 14.4
Sails weathered in the Dutch manner, but enlarged towards the extremities	14	7½	22½	123	75	10.65	12.59	7.99	5.05	10 : 6.1	10 : 8.5	10 : 15.8
	15	10	25	117	74	11.08	13.69	8.20	..	10 : 6.3	10 : 8.1	10 : 16.2
	16	12	27	114	66	12.09	14.23	7.99	..	10 : 5.8	10 : 8.4	10 : 15.8
	17	15	30	96	63	12.09	14.78	7.62	..	10 : 6.6	10 : 8.2	10 : 15.1
Eight sails, being sectors of ellipses in their best positions	18	12	22	105	64½	16.42	27.87	10.59	8.54	10 : 6.1	10 : 5.9	10 : 12.4
	19	12	22	99	64½	18.06	..	11.65	11.46	10 : 5.9	..	10 : 10.1
	1	2	3	4	5	6	7	8	9	10	11	12

Remarks on the above Table

(102.) Upon the results of these experiments Mr. Smeaton remarks :

1. That the sails set at the angle with the axis, proposed as the best by Parent and others, viz. 55°, were found to have the least effect of any that were tried.

2. That when the angle of the sails with the axis was increased from 55° to between 72° and 75°, the power or product was augmented in the proportion of 31 to 45.

3. That if nothing more were requisite than to cause the sails to acquire a certain degree of velocity by the wind, the position recommended by Parent would be the best ; but if the sails are intended with given dimensions to produce the greatest effect possible in a given time, we must, if plans are made use of, confine the angle within the limits of from 72° to 75°.

4. That the variation of a degree or two, when the angle is near the best, is but of little consequence, and that when the wind falls upon a concave surface, it is an advantage to the power of the whole, although every part taken separately would not be disposed to the best advantage.

5. That from several trials on a larger scale, he has found the following angles to answer as well as any. The radius is supposed to be divided in six parts, and one-sixth, reckoning from the centre, is called 1, the extremity being denoted 6.

Number.	Angle with the axis.	Angle with the plane of motion.
1	72°	18°.
2	71	19
3	72	18 middle.
4	74	16
5	77½	12½
6	83	7 extremity."

The author further remarks, that a broader sail re-

quires a larger angle, and that when the sail is broader at the extremity than near the centre, this shape is more advantageous than that of a parallelogram, and that the figure and proportion of the enlarged sails which he found best to answer on a large scale, were when the extreme bar was one-third of the radius or whip, and divided by the whip in the proportion of 3 to 5. In the latter case the triangular or leading sail was formed of board from the point downwards one-third of its height, the rest with cloth as usual.

Many have imagined that the more sail the greater the advantage, and have therefore proposed to fill up the whole area, and by making each sail a sector of an ellipsis, according to Parent, to intercept the whole cylinder of wind, and thereby to produce the greatest effect possible ; but from our author's experiments it appears that when the surface of all the sails exceeded seven-eighths of the area, the effect was rather diminished than augmented. Hence he concludes, that when the whole cylinder of wind is intercepted, it cannot produce the greatest effect for want of proper interstices to escape.

Mr. Smeaton states, that it is certainly desirable that the sails of wind-mills should be as short as possible ; but it is equally desirable that the quantity of cloth should be the least that may be, to avoid damage by sudden squalls of wind. The best structure therefore for large mills is when the quantity of cloth is the greatest that can be in a given circle : on this condition that the effects hold out in proportion to the quantity of cloth ; for otherwise the effect can be augmented in a given degree by a lesser increase of cloth upon a larger radius than would be required if the cloth were increased upon the same radius.

Manufactures.

The most useful figure therefore for practice is that of No. 9 or 10 in the Table, as has been experienced in several mills upon a large scale.

Mr. Smeaton having in the preceding experiments made a comparison of the power of different surfaces and angles of weather with the same velocity, next pro-

ceeded to determine the effect according to the different velocities of the wind. These experiments were made with the same apparatus as the former ones, and the sails were of the same kind as those of Nos. 10, 11, and 12 in the preceding Table.

Machinery.

TABLE II.—Experiments to determine the Difference of Effect with different Velocities of the Wind.

Number.	Angle at the extremity.	Velocity of the wind in a second.	Turns of the sails unloaded.	Turns of the sails at the maximum.	Load at the maximum.	Greatest load	Product.	Maximum load for the half velocity.	Turns of the sails therewith.	Product of lesser load and greater velocity.	Ratio of the two products.	Ratio of the greatest velocity to the velocity at maximum.	Ratio of the greatest load to the load at maximum.
1	5°	ft. in. 4 4½	96	66	lbs. 4.47	lbs. 5.37	295	..	..	..	..	10 : 6.9	10 : 8.3
2	5	8 9	207	122	16.42	18.06	2003	4.47	180	805	10 : 27.3	10 : 5.9	10 : 9.1
3	7½	4 4½	..	65	4.62	..	300	..	..	..	..	..	..
4	7½	8 9	..	130	17.52	..	2278	4.62	180	832	10 : 27.8	..	..
5	10	4 4½	91	61	5.03	5.87	307	..	..	..	..	10 : 6.7	10 : 8.5
6	10	8 9	178	110	18.61	21.34	2047	5.03	158	795	10 : 26	10 : 6.2	10 : 8.7
1	2	3	4	5	6	7	8	9	10	11	12	13	14

Remarks on Table II.

(103.) The results of these experiments Mr. Smeaton enters into at considerable length. We shall, however, only give here the laws (or, as he terms them, maxims) which have resulted from his investigations and comparisons, again referring the reader who is desirous of examining the detail, to vol. li. of the *Philosophical Transactions*, or the *Abridgement*, vol. xi.

Maxim 1. The velocity of wind-mill sails whether unloaded or loaded, so as to produce a maximum, is nearly as the velocity of the wind, their shape and position being the same.

2. The load at the maximum is nearly, but somewhat less than, as the square of the velocity of the wind, the shape and position of the sails being the same.

3. The effects of the same sails at a maximum are nearly, but somewhat less than, as the cubes of the velocity of the wind.

4. The load of the same sail at a maximum is nearly as the squares, and their effect as the cubes of their number of turns in a given time.

5. When sails are loaded so as to produce a maximum at a given velocity, and the velocity of the wind increases in a slight degree, the load continuing the same, the increase of effect will be nearly as the squares of those velocities; but when the velocity of the wind is increased to double, the effects will be nearly as 10 to 27½; and when the velocities compared are more than double of that where the given load produces a maximum, the effects increase nearly in the simple ratio of the velocity of the wind. Hence he concludes that wind-mills of the different descriptions, for raising water, drainage, &c., lose much of their effect when acting against one invariable opposition.

6. In sails of a similar figure and position the number of turns in a given time will be reciprocally as the radius or length of the sail.

7. The load at a maximum that sails of a similar figure and position will overcome at a given distance from the centre of motion will be as the cube of the radius.

8. The effects of sails of similar position and figure

are as the square of the radius. Hence it follows that augmenting the length of the sail, without augmenting the quantity of cloth, does not increase the power: because what is gained by the length of the lever is lost by the slowness of motion. Hence, also, if sails are increased in length, the breadth being the same, the effect will be as the radius.

9. The enlarged sails are superior to those of the common Dutch construction, which, Mr. Smeaton further remarks, perfectly agrees with the practical observations he has had opportunities of making on this subject.

10. The velocity of the extremities of the common Dutch sails as well as of the enlarged sails, either when unloaded, or even when loaded, to a maximum, is considerably greater than that of the wind itself.

Mr. Smeaton in this way made out a Table of the velocities of the wind according to their common appellations, by ascertaining the exact ratio of the extremity of the particular sail he observed with the velocity of the wind; this has been already given in our Essay on PNEUMATICS.

(104.) *Clothing the sails.*—In the above experiments the sails have in each case been full set; it is, however, necessary, when the wind is very high, to take in a part of the cloth, and there are usually four states in which it can be set according to the velocity of the wind and quantity of work to be performed, which are termed *full sail*, *quarter reef*, *sword point*, and *dagger point*. The mode of effecting this is by ropes fastened to the sail at the three points *a b c*, (pl. vi. fig. 6,) which pass either through rings, or over the ends of the bars which project beyond the piece *M B'*, and by releasing these lines the sails may be very readily reefed up to any of the positions shown by the dotted lines in the figure.

It is, of course, necessary when the quantity of sail is varied that the mill should be stopped, an operation which is often attended with a great deal of inconvenience and loss of time. Those who occupy mills well know the danger they are often exposed to from sudden squalls of wind and hard gales continuing and increasing while the sails are clothed and going, which are often

Clothing the sails.

Manufac-
tures.

incapable of outriding the storm. The shafts, if not wrung off at their necks by the too frequent application of the brake, are so crippled and weakened as to be rendered unfit to be trusted, after repeated injuries of this kind, and various accidents arise in consequence, often attended with loss of life. In addition to this the uncertainty of the wind and danger in long and dark nights, often deter the miller from grinding when he is in the greatest need, and the time and trouble necessary to stop the mill and alter the cloth so frequently in unsettled weather, are such as to disable him from doing a great proportion of the work which could otherwise be done at those times.

These various inconveniences attending the common mode of clothing sails have led to several inventions, to enable the miller to clothe the sails in an expeditious manner, while they are in motion, and several patents have been taken out for different modes of accomplishing this purpose, of which the three following have been most approved and adopted.

Self-adjust-
ing sails.

Mickle's
method.

(105.) *Self-adjusting Sails.*—One of the first attempts at accomplishing this object was by Mr. Andrew Mickle, the inventor of the threshing-machine, in 1772. The length of the sail is here divided into eleven compartments, by the bars forming a number of oblong openings, which are each filled up by a square frame of wood covered with canvass, and mounted on pivots at their ends, one pivot turning in a hole in the whip, and the other in the bar which lies parallel to it, in the manner of a Venetian blind; the pivots are not placed in the middle of the breadth of the frames, but at one-third from the edge, towards the shaft or axle of the sails. On the end of each pivot which enters the whip, a small roller is fixed, round which a chain passes, and its end is attached to a steel spring, placed at right angles to the whip, and in the direction of the length of the canvassed frames. Now if the wind blows too hard it acts to turn the frames edgewise, in which case the wind passes through the sails, and exerts less force to turn them round, but as soon as the wind becomes moderate, the steel spring brings up the frames into a plane presenting their whole surface to its action. A rod of iron extends the whole length of the whip, and is connected with several springs, to afford the means of strengthening or diminishing their action according to the season of the year. This rod is formed with a screw and nut at its outer extremity to enable the miller to adjust the strength of the springs conveniently, from the circular gallery surrounding the outside of the mill.

Bywater's
patent.

Plate viii.
fig. 7, 8.

(106.) Mr. John Bywater of Nottingham took out a patent in 1804 for a method of clothing and unclothing the sails of wind-mills while in motion; which consisted in rolling or folding them up to the whip by means of cylinders or rollers, which extended the whole length of the sails, and were put in motion when required by a system of wheel-work connected with the shaft in the following manner. A ring of iron, *a*, pl. viii. fig. 7, about four inches wide, and three-quarters of an inch thick, is attached to the main shaft (and concentric with it) a short distance behind the whip. A bevelled wheel, *b*, without arms, is made so as to revolve easily upon the circumference of the ring, and a spur wheel without arms is made to turn upon four pins or ears in the back of the ring. The arrangement of this part will be better understood from fig 8, which is a back view of the ring of iron; *c* is the spur wheel which turns upon the pins; *d d d d* and *e e e e* are four pinions, which are

attached to a spindle, having at their other extremity bevelled pinions, *f f f f*, fig. 7, which work in similar ones attached to the rollers, *P P*. Upon these cylinders the sails are rolled up; they are about three inches diameter, made of wood, one being placed at the outside of the leading edge of each sail. A gudgeon from the end of each cylinder turns in an iron fastened to the shaft head, and is kept in its place by a nut screwed to the end. The other end has a gudgeon, which turns in the eye of the cross iron, *g g*, fixed on the end of the whips. Four cylinders, one of which is shown at *R* in the figure, similar to *P P*, are placed on the inside of the whips, which have ropes round their circumferences, and fastened to the edges of the cloth of the sail, so that by the revolution of this cylinder the sail is clothed. The cylinder has a bearing at one end in the cross iron, at the end of the whip, and at the other, either in a projecting part of the iron rim, or in the shaft-head; it has a small bevelled wheel, *h*, which works in the bevelled wheel *b*, upon the iron ring, by means of which motion is conveyed to it.

The Machinery in the ordinary state of the mill revolves with the shaft undisturbed, and is only put in action when any variation of the quantity of cloth is required, which is done in the following manner. Suppose the mill fully clothed, and that it is required to diminish the quantity of canvass; a lever, which is fastened to the bracing or fencings, and which is weighted so as to hang vertically, is brought into a horizontal position by means of a string attached to the end within the mill. In this position it engages a stud, *s*, upon the spur wheel, and prevents its motion. The bevelled wheel, *b*, and iron rim of course continue to revolve with the shaft, and, consequently, give motion to the small pinions, and with them the cylinder *PP* which will continue to wind up the cloth until the end of the lever is disengaged from the stud, which at once stops the action of the Machinery, so that the miller, by letting go the string, can at any time leave the cloth on the sail where he chooses. In a similar manner, when it is necessary to clothe the sails, a lever is made to engage a stud, *t*, upon the bevelled wheel, and, by stopping it, to give motion to the bevelled pinion and cylinder, *R* which winds up the ropes and draws the cloth gently forward upon the bar. In this way the miller has the action of the Machinery completely at command, so that by pulling one or the other string he may adjust the quantity of sail exactly to the strength of the wind and nature of the work the mill has to perform.

In order to prevent the springing of the cylinders, which they are liable to when of great length, a stay of wood is fixed at *n*, having in the inside room enough to allow the cloth to be rolled up. As the cords, *o o o*, &c., which go over to the edge of the shrouds, are liable to get loose in dry weather, a cord passing over a spring of any sort or shape placed under the sail, is fastened to and wound about the upper ends of the cylinders in a direction contrary to the strings and cloth, this, by making every thing tight, renders the action of the Machinery more steady and instantaneous.

Mr. Bywater also mentions, in the specification of his patent, a mode of folding up the cloths instead of rolling them up, by means of which he does away with one set of rollers. The manner of effecting it he thus describes:—"One end of the cloth must be fastened to the whip, and lines passed across the outside of it through loops fastened to its edge, and continued over the edge of the

Machinery.

Manufactures. shrouds, and connected with a cylinder or roller of any shape placed under the sail or elsewhere; the other ends of the lines must also be connected with the said cylinder or roller; and when the cloth is drawn up in folds towards the whip, so much of these lines will be rolled on the cylinder one way, and off from it on the other, as will be sufficient to let out the cloth again when the same cylinder, turned the contrary way, draws the cloth on the sail. By this mode four cylinders with their appendages are avoided, the works being in other respects the same as in rolling the cloths; but since folding gives a surface much inferior in many respects to rolling, and leads to inconveniences and accidents from which the rolled surface is free, the inventor advises the rolling, rather than from a small saving to incur the inconveniences of folding.

This method of clothing wind-mill sails possesses considerable advantages over the common mode, not only in avoiding the loss of time and frequent danger attending it, but they will afford the miller more power than prudence would allow him to adopt, without the constant and ready control which by this Machinery he will always be able to exercise over the wind.

Cubit's patent sails. (107.) Mr. William Cubit, Civil Engineer, took out a patent in the year 1807, for a method of equalizing the motion of the sails of wind-mills, which, in some measure, resembles that of Mr. Mickle, the sails being composed of a series of vanes or valves suspended at their ends by pivots in the framework of the sails; and these vanes are contrived to present a greater or less surface to the wind, according as it acts with more or less force upon them. If the wind be very strong, the vanes by its impulse turn their edges to it, and their surfaces parallel to the direction of the wind, and would, consequently, remain stationary, or, at least, have but little motion. To obviate this inconvenience, he employs an apparatus which causes the vanes to present their flat surfaces to the wind, or such portion of their surfaces as may be desirable.

Fig. 9. Fig. 9 represents a set of vanes in which A A show the valves turned to the wind, and their surfaces exposed at right angles to it. B B exhibits the vanes as close reefed, with their edges to the wind, so that it can have no effect upon them, except on their edges. In the drawing, the vanes are exhibited as having the whip down the middle, with valves on both sides; but it is evident that the vanes may be constructed with the whip placed in the usual way, and have valves on one side only.

Fig. 10. Fig. 10 is a section through the wind shaft, exhibiting the apparatus for regulating the vanes. A is the wind shaft, which is bored through its centre to admit an iron rod, B, to pass freely through it; one end of this rod has a knol or onion on it, which turns in a box, c, so that it can be moved endwise, while it continues to revolve. The box c is fastened to a toothed rack, D, whose teeth engage those of a pinion, E, upon the spindle of which is a sheave, F, with a groove on its circumference to receive a rope, G, to which is hung the weight W. This weight serves to regulate the force of the wind upon the valves, and may be adjusted to the nature of the work to be performed by the mill. On the other end of the rod is fixed a plate of iron, K, with ears upon it, projecting from each side, in which are fixed the bridles or leaders, L L, which permit the levers M M to describe a curve with their ends, while the iron rod B moves in a straight line. N N are two uprights or props, on the ends of which the levers M M

VOL. VII.

move, and communicate the motion of the iron rod B Machinery. to the racks P P. These racks engage the pinions Q Q, on the axis of which (according to one method here described, fig. 10.) is fixed a strong iron lever or crank Fig. 10. c; the end of this is attached to a slider S. Each vane has a small lever projecting from it, which is fixed in the slider by a pin or gudgeon, so that by the motion of the slider the vanes present a different angle to the wind.

The other method of regulating the vanes is shown Fig. 11. in fig. 11, where, instead of levers, the vanes have a pinion attached to them, which engages the teeth of a rack or slider T.

The operation of this apparatus will be readily understood by imagining the rope G pulled down so as to cause about three-quarters of a revolution of the sheave F. The pinion E will put in motion the rack D and rod B, which brings the levers into the position represented by the dotted lines: the rack P P will have turned the pinions till the sliders S or T (according to whichever method may be used) bring the vanes into such a position that their whole surface is presented to the wind; therefore, if a weight be hung upon the line G, it will keep the surface of the vanes to the wind, until the strength of it is such as to raise the weight, when the vanes will be more or less opened until the pressure upon the inclined surface is reduced so as to balance the weight; by this means the force of the wind beyond that sufficient to raise the weight, will not produce any additional velocity, and a degree of regularity will be attained which can never be produced by the ordinary method.

Several other methods of equalizing the sails of wind-mills have been invented; but those above described are the only ones we are aware of which have been brought into practice, and these, although allowed by millers to possess considerable advantage over the common mode, are, probably from their additional expense, not brought by any means into general use.

(108.) *Horizontal wind-mills.*—In consequence of the Horizontal wind-mills. very small angle at which the sail of the vertical wind-mill is inclined to the direction of its motion, which at a medium cannot be estimated at more than 20° , and of which angle, the sine which represents the force, to give motion to the sails, scarcely exceeds one-third of the radius, much of the power of the wind is necessarily lost; and hence have arisen endeavours to substitute horizontal for vertical sails, under a mistaken idea that more power would be acquired by the former than by the latter. Some constructions of this kind have been carried into effect, and are, we believe, still at work, or were very recently, one at Battersea, and one at Margate. As they are, however, now by universal consent admitted to be inferior to the vertical ones, it would be uselessly filling our pages, and unpromptly engaging the attention of the reader to enter into a description of them. We therefore beg to refer those who may be desirous of obtaining information on this subject to the *Theatrum* of the celebrated Leopold, and the *Repertory of Arts*, in each of which will be found a great number of contrivances for this purpose.

(109.) Mr. Smeaton, in his paper to the Royal Society on the power of wind to turn mills, which we have before mentioned, enters into the following investigation, in which he proves in a very satisfactory manner the cause of the disadvantages attending this mode of applying the power of wind. He remarks in the commencement of his

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tures.
Smeaton's
remarks on
horizontal
wind-mills.

paper that "observations upon the effects of common wind-mills with oblique vanes, have led many to imagine that could the vanes be brought to receive the direct impulse, like a ship sailing before the wind, it would be a very great improvement in point of power; while others attending to the extraordinary effects of oblique vanes, have been led to imagine that oblique vanes applied to water-mills would as much exceed the common water-wheels, as the vertical wind-mills are found to have exceeded all attempts towards an horizontal one. Both these notions, but especially the first, have so plausible an appearance, that of late years there has seldom been wanting those who have assiduously employed themselves to bring to bear designs of this kind; it may not, therefore, be unacceptable to endeavour to set this matter in a clear light."

Fig. 12.

Let AB , fig. 12, be the section of a plane, upon which the wind blows in the direction CD , with such a velocity as to describe a given space BE , in a given time, (suppose one second,) and let AB be moved parallel to itself, in the direction CD . Now if the plane AB moves with the same velocity as the wind; that is, if the point B moves through the space BE in the same time that a particle of air would move through the same space; it is plain that, in this case, there can be no pressure or impulse of the wind upon the plane; but if the plane moves slower than the wind, in the same direction, so that the point B may move to F , while a particle of air, setting out from B at the same instant, would move to E , then BF will express the velocity of the plane; and the relative velocity of the wind and plane will be expressed by the line FE . Let the ratio of FE to BE be given; (suppose $2:3$;) let the line AB represent the impulse of the wind upon the plane AB when acting with its whole velocity BE ; but, when acting with its relative velocity FE , let its impulse be denoted by some aliquot part of AB , as for instance $\frac{2}{3}AB$; then will $\frac{2}{3}$ of the parallelogram AF represent the mechanical power of the plane; that is, $\frac{2}{3}AB \times \frac{1}{3}BE$.

Fig. 13.

Secondly, let IN , fig. 13, be the section of a plane, inclined in such a manner that the base IK of the right angled triangle IKN may be equal to AB , and the perpendicular $NK = BE$; let the plane IN be struck by the wind, in the direction LM , perpendicular to IK , then, according to the known rule of oblique forces, the impulse of the wind upon the plane IN , tending to move it according to the direction LM or NK , will be denoted by the base IK ; and that part of the impulse tending to move it according to the direction IK , will be expressed by the perpendicular NK . Let the plane IN be movable in the direction of IK only; that is, the point I in the direction IK , and the point N in the direction NQ parallel thereto. Now it is evident that if the point I moves through the line IK , while a particle of air, setting forward at the same time from the point N , moves through the line NK , they will both arrive at the point K at the same time; and, consequently, in this case also, there can be no pressure or impulse of the particles of air upon the plane IN . Now let IO be to IK as BF to BE ; and let the plane IN move at such a rate, that the point I may arrive at O , and acquire the position OQ at the same time that a particle of wind would move through the space NK : as OQ is parallel to IN , (by the properties of similar triangles,) it will cut NK in the point P , in such a manner, that $NP = BF$ and $PK = FE$; hence it appears, that the plane IN by acquiring the position OQ , withdraws

itself from the action of the wind, by the same space NP , Machinery. that the plane AB does by acquiring the position FG ; and, consequently, from the equality of PK to FE , the relative impulse of the wind PK upon the plane OQ , will be equal to the relative impulse of the wind FE upon the plane FG ; and since the impulse of the wind upon AB with the relative velocity FE , the direction BE is represented by $\frac{2}{3}AB$; the relative impulse of the wind upon the plane IN , in the direction NK , will in like manner be represented by $\frac{2}{3}IK$; and the impulse of the wind upon the plane IN , with the relative velocity PK , in the direction IK , will be represented by $\frac{2}{3}NK$; and consequently the mechanical power of the plane IN , in the direction IK , will be $\frac{2}{3}$ of the parallelogram IQ ; that is $\frac{2}{3}IK \times \frac{1}{3}NK$; that is, from the equality of $IK = AB$ and $NK = BE$ we shall have $\frac{2}{3}IQ = \frac{2}{3}AB \times \frac{1}{3}BE = \frac{2}{3}AB \times \frac{1}{3}BE = \frac{2}{3}$ of the area of the parallelogram AF . Hence we deduce this general proposition, *That all planes, however situated, that intercept the same section of the wind and having the same relative velocity, in regard to the wind, when reduced into the same direction, have equal powers to produce mechanical effects.*

For what is lost by the obliquity of the impulse is gained by the velocity of the motion.

Hence it appears, that an oblique sail is under no disadvantage in respect of power, compared with a direct one, except what arises from a diminution of its breadth in respect to the section of the wind, the breadth IN being obliquely reduced to IK .

The disadvantage of horizontal wind-mills, therefore, does not consist in this; that each sail, when directly exposed to the wind, is capable of a less power than an oblique one of the same dimensions, but that in a horizontal wind-mill, little more than one sail can be acting at once; whereas in the common wind-mill, all the four act together; and, therefore, supposing each vane of a horizontal wind-mill of the same dimensions as each vane of the vertical, it is manifest the power of a vertical mill with four sails, will be four times greater than the power of the horizontal one, let its number of vanes be what it will. This disadvantage arises from the nature of the thing; but if we consider the further disadvantage that arises from the difficulty of getting the sails back again against the wind, &c., we need not wonder if this kind of mill is in reality found to have not above $\frac{1}{8}$ or $\frac{1}{10}$ of the power of the common sort, as has appeared in some attempts of this kind.

(110.) *Water-mills.*—It has been already explained Water-mills. that by the term water-mill, as applied in this Chapter, is only to be understood that part of the general Machine employed in producing a first rotation, without any reference to the Machinery intended to be driven by it. We have only here, therefore, to speak of the wheels, and show their construction, and the advantages or disadvantages of their different forms and modes of action.

We have already, under the article in which water is treated of as a first mover, defined the different kinds of water wheels, which, as far as the figure and construction is concerned, may be reduced to two or at most to three. The balance and overshot wheel being precisely the same in form, and the undershot and breast wheel differing only in the one being an open wheel with floats, while the other is close soled, and sometimes close shrouded; that is, it is close boarded on its circumference which is called the soling, and sometimes also closed in on its sides to the depth of the floats which is called the shrouding.

Manufac-
tures.

Water wheels were formerly, and are still occasionally, made of wood; but they are now more commonly made of iron. When overshot wheels are made of this material, two iron wheels are first cast whole or framed after the manner already described for fly wheels, &c.; and to the extremity of their arms, or to their rims, the shrouding is bolted and screwed. These wheels being fixed on an axle at a proper distance from each other, the parts forming the soling and buckets are also bolted and screwed between them to flanches formed for the purpose, by which the whole becomes one wheel.

Pl. vii.
Fig. 1.

The form of the buckets is considered a matter of considerable importance: an idea of their shape and arrangement may be formed by the dotted lines in fig. 1; but a more particular description of their figure and construction is given below.

A slight consideration of the nature and action of the overshot wheel is sufficient to convince the reader of the impossibility of constructing the buckets so as to remain completely filled with water till they reach the bottom of the wheel; indeed, if the buckets were formed by partitions directed to the axis of the wheel, the whole water must run out by the time they had descended to the level of the axis, and of course there would be a great diminution in the mechanical effect. Millwrights have therefore turned their attention to finding the best figure to be given to the partitions forming the buckets; that is, to the finding such form as shall enable them to retain their water as long as it is useful and no longer, in their descent towards the lower part of the wheel. We say as long as it is useful; for it is plain, if it could be retained to the bottom, as it could not then immediately escape, a part of it would be carried up and would of course counteract the effect of the descending water. It would occupy considerable space to attempt to describe here one half of the numerous contrivances which have been recommended with a view of accomplishing this object, we shall therefore content ourselves with describing one or two only of those which are esteemed the best.

Construc-
tion of the
buckets of
water
wheels.
Fig. 3.

(111.) *Construction of the buckets.*—In fig. 3, A M represents the part of the shrouding or ring of buckets of an overshot wheel of forty buckets. The form of one of these is shown by G O F A B C D; in which the sole of one bucket A F should be $\frac{2}{3}$ of A E, the depth of the shrouding, and the shoulder A B of the bucket should be one half of A E. The arm B C of the bucket must be so inclined to the shoulder A B that H C perpendicular to A H F at H may be $\frac{2}{3}$ of A E; and the wrist of the bucket C D must be so inclined to B C n, the direction of the arm, that D n may be $\frac{1}{3}$ of E n.

From this construction it follows that the area H A B C is very nearly equal to D A B C; so that the water which will fill the space H A B C will all be contained in the bucket when it comes into such a position that A D is a horizontal line; and the line A B will then make an angle of 35° with the vertical, or the bucket will be 35° from the perpendicular passing through the axis of motion. If the bucket descend so much lower, that one-half of the water runs out, the line A B will make an angle of about $24\frac{1}{2}^\circ$ with the vertical. Therefore the wheel filled to the degree now mentioned, will begin to lose water at about $\frac{1}{8}$ of the diameter from the bottom, and half of the water will be discharged from the lowest bucket about $\frac{1}{2}\frac{1}{4}$ of the diameter further down. Had a greater proportion of the buckets been filled with water when they were under the spout, the discharge would have begun at a greater height from the bottom, and a

greater portion of the whole fall of water would be lost. Machinery. The loss by the preceding construction is less than $\frac{1}{10}$, supposing the water to be delivered into the wheel quite at the top, and may be estimated at about $\frac{1}{12}$; for the loss is as the versed sine of the angle which the radius of the bucket makes with the vertical.

The versed sine of 25° is 0.18085, or nearly $\frac{1}{5}$ of the radius, or $\frac{1}{10}$ of the diameter. Had only $\frac{1}{2}$ of this water been supplied to each bucket as it passed the spout, it would have been retained for 10° more of a revolution, and the loss of fall would have only been about $\frac{1}{18}$.

(112.) *Another method.*—Other millwrights divide the bucket by a partition, concentric with the sole and rim, and of such an altitude, as to make the inner and outer portions of the bucket of nearly equal capacity. In consequence of this contrivance, the fluid is longer retained in the descending buckets; and when the supply of water is very scanty, a proper adjustment of the apparatus which regulates the position of the spout will direct nearly all the water into the exterior buckets, and thus, by placing it at a greater distance from the axis, sensibly augment its mechanical energy. Dr. Robison, in speaking of this construction, suggests also that the breadth of the buckets, or the rim of the wheel, should be tolerably large, that the quantity of water received from the spout may not nearly fill the buckets. And in order to prevent the air from impeding the rising buckets, or, as the millers term it, the buckets from sucking up the tail water, he advises that the shoulder or strut of each bucket be perforated with a few holes. As to the spout which conveys the water, it should be considerably narrower than the breadth of the wheel; and the distance of the spout from the receiving bucket should also in general be two, three, or four inches, that the water may be delivered with a velocity a little exceeding that of the rim of the wheel, otherwise the wheel will be retarded by the impulse of the buckets against the stream, and the dashing of the water over would occasion a diminution of power.

With respect to variations in the fall of water, since the active pressure is measured by the pillar of water reaching from the horizontal plane where it is delivered on the wheel, to the horizontal plane where it is spilled by the wheel, it has been concluded, that the pressure must be proportional to the wheel; and, therefore, the water must be delivered as high, and retained as long as possible. This maxim, however, is subject to limitations, and is not perhaps consistent with sound theory. When the fall is exceedingly great, a wheel of an equal diameter becomes enormously big, and extremely expensive. In cases like this, where we are unwilling to lose any part of the force of a full stream, the best form of a bucket wheel is an inverted chain pump, or *chain of buckets*. Gregory, *Mechanics*, vol. ii.

(113.) *Of the velocity of an overshot wheel.*—This is a matter calling for great care and attention; different authors having arrived at very opposite conclusions respecting it. Theory seems to indicate that an overshot wheel does the more work, as it moves slower. The popular reasoning adduced to prove this has been of the following kind. Suppose that a certain wheel has thirty buckets, and that six cubic feet of water are delivered in a second on the top of the wheel, and discharged without any loss by the way, at a certain height from the bottom. Let this be the case, whatever is the rate of the wheel's motion, the buckets being of a sufficient capacity to hold all the water which falls into them. Suppose this wheel

Velocity of
overshot
water
wheels.

Manufac-
tures.

employed to raise a weight of any kind, water, for instance, in a chain of thirty buckets, to the same altitude and with the same velocity. Suppose, further, that when the load on the rising side of the Machine is one half of that on the wheel, the wheel makes four revolutions in a minute, or one turn in fifteen seconds. During this time, 90 cubic feet of water will have flowed into the thirty buckets, and each have received three cubic feet. In that case, each of the rising buckets contains one and a half feet; and 45 cubic feet are delivered into the upper cistern during one turn of the wheel, or 180 cubic feet in one minute.

Now, suppose the Machine so loaded, by making the rising buckets more capacious, that it makes only two turns in a minute, or one turn in thirty seconds. Then each descending bucket must contain six cubic feet of water. If each bucket of the rising side contain three cubic feet, the motion of the Machine would be the same as before. Our Machine would, therefore, continue to make four turns in a minute, and would deliver 90 cubic feet during each turn, or 360 in a minute. But, by supposition, it is making only two turns in a minute, which *must* proceed from a greater load than three cubic feet of rising water in each rising bucket. The Machine must, therefore, be raising *more* than 90 feet of water during one turn of the wheel, and *more* than 180 in a minute. Thus it appears, that if the Machine is turning twice as slow as before, there is more than twice the former quantity in the rising buckets; and more will be raised in a minute by the same expenditure of power. In like manner, if the Machine go three times as slow, there must be more than three times the former quantity in the rising buckets, and more work will be done.

These remarks are sufficient to show, in general, the advantage of slow motion; but they do not, it must be acknowledged, point out in any degree the relation between the rate of motion and the work performed, nor even the principle on which it depends. It is, however, sufficiently obvious, that there is not in the nature of things a maximum of performance attached to any particular rate of motion. All, therefore, we have to do is to load the Machine, and thus to diminish its speed till other physical circumstances interpose, and these will necessarily occur. In the action of a wheel and pinion, though made with the greatest judgment and care, inequalities cannot be avoided; and these increase by the change of form occasioned by wear, and all irregularity of this kind is more sensibly felt in slow motions and with great weights, than with greater velocities and less weights, and thus practical defects step in and prevent us here, as in other cases to which we have already referred, from pursuing advantages on one hand without introducing disadvantages on the other. The great question is, therefore, to determine the point where the maximum effect is produced; and as this depends so much on circumstances, it can be only determined when these circumstances are known, and then only by the experienced millwright. All calculations on such subjects are vain and useless. The following remarks, however, from Gray's *Treatise on Practical Mill-Work*, may be quoted with advantage.

Maximum
load of
overshot
wheels.

(114.) *Of the maximum load.*—The maximum load for an overshot wheel is that which reduces the circumference of the wheel to its proper velocity; which is known by dividing the effect it ought to produce in a given time by the space intended to be described by the circum-

ference of the wheel in the same time, and is equal to the load required, including the friction and resistance of the Machinery.

The greatest velocity that an overshot wheel is capable of, depends jointly upon the diameter or height of the wheel and the velocity of falling bodies; for it is plain that the velocity of the circumference can never be greater than to describe a semicircumference, while a body let fall from the top describes the diameter, nor even quite so great, as the difference in point of time must always be in favour of the diameter. Thus supposing the diameter of the wheel to be 16 feet one inch, a heavy body would fall through this space in one second; but such a wheel could never arrive at this velocity, or make one turn in two seconds, nor could an overshot wheel ever come near it; because, after it has acquired a certain velocity, great part of the water is prevented from entering the bucket, and part is thrown out again by the centrifugal force. In theory we may suppose a wheel to be made capable of overcoming any resistance whatever; yet as, in practice, it is necessary to make the wheel and buckets of some certain and determinate size, we always find that the wheel will be stopped by such a weight as is equal to the effort of the water in all the buckets of a semicircumference put together. This may be determined from the structure of the buckets themselves: but, in practice, an overshot wheel becomes unserviceable long before this time, for when it meets with such an obstacle as diminishes its velocity to a certain degree, its motion becomes irregular; but this never happens till the velocity of the circumference is less than two feet in a second, when the resistance is equable.

From the above observations we may easily deduce the force of water upon breast wheels, &c. But, in general, all kinds of wheels, where the water cannot descend through a given space unless the wheel moves with it, are to be considered as balance or overshot wheels; and those which receive the impulse or shock of the water, whether in an horizontal, oblique, or perpendicular direction, are to be considered as undershot. Hence a wheel on which the water strikes at a certain point below the surface of the head, and after that descends in the arch of a circle, pressing by its gravity upon the wheel, the effect of such a wheel will be equal to that of an undershot, whose head is equal to the difference of level between the surface of the water in the reservoir and the point where it strikes the wheels, added to that of an overshot, whose height is equal to the difference of level between the point where it strikes the wheel and the level of the tail water.

(115.) *Undershot wheels.*—Under this head are included such wheels as are impelled by the motion of the water independently of its weight, the theory of which has given rise to a great variety of opinions, discussions, and experiments. De Parcieu and Bossut have examined the best angle for the float boards to be fixed at, with respect to the radius of the wheel, in order to produce the best effect; and both agree in stating that a sensible advantage is gained by inclining them to the radius of the wheel at about an angle of 20° ; so that each float when lowest shall not be vertical, but be inclined towards the stream at the above angle. Such inclination, it is said, causes the water to accumulate along the float boards so as in some degree to act by its weight, and it is for this reason recommended that the floats should be made broader than the vein of water

Machinery.

Manufactures. interrupted by them is deep. This inclined float is now frequently but not generally adopted, and upon the whole, perhaps, the advantages attending it are not so great as were supposed by its first projectors.

Construction. *Construction of undershot wheels.*—These wheels, like the overshot wheels, are now generally made of iron, except the floats which are commonly of wood. Two iron wheels in this case, as in the former, are first cast or framed together, and at equal distances along their rims mortises are formed through, into which are securely fixed strong pieces of elm called *starts*. Now the two wheels being fixed on their axles at the proper distance, the floats are fixed across to these starts by proper bolts and nuts, the floats being commonly left projecting beyond the breadth of the wheel about one-eighth of their whole length on each side. See fig. 6.

Fig. 6. The breast wheel differs from this in its construction, only in being close soled and shrouded, as already explained, and of course, in this case, the floats have no projections.

Effect. (116.) *On the effect of undershot wheels.*—The great question relative to the best effect of undershot wheels, has always been the ratio that ought to subsist between the velocity of the wheel and that of the water; and in the *Treatise on HYDRODYNAMICS* in the preceding parts of this Work, Mr. Smeaton's experiments on this subject have been given at considerable length; it is only, therefore, for the sake of avoiding the inconvenience of frequent reference, that we give the following analysis of those results in this place, but for the more minute detail of them the reader must consult the Article in question.

First, it may be observed, that in order to compute the effects of water wheels, it is necessary to know what is the real velocity of the water that impinges on the wheel, the quantity expended in a given time, and what quantity of power is lost by the friction of the Machinery. This may be done as follows: to ascertain the force of any moderate stream of water, let it be obstructed by a dyke or dam across the stream, so as to force all the water through a trough or open spout into a square vessel or reservoir; measuring the quantity of water that runs into this reservoir in any given time, as for example, a second or minute. Multiply this quantity by the number of seconds or minutes in an hour, thus the whole impulse of such stream of waters at any given height, and of a medium breadth, may be readily ascertained. In rivers that are too large to be measured in this way, the force or impulse may be calculated thus: Let a narrow oblong square cistern, or reservoir, be fastened in the river with one end of it directed to the stream, having its upper edge a little above the surface, that no water can get into it over the top. In the end of this cistern, facing the stream of the river, is to be fixed a long spout of wood open above the upper edges of it, being level with the surface of the river, and at the same declivity with the current. Then the water will have the same velocity within the spout as the river on its outside; therefore by measuring the quantity of water that runs into the reservoir through the spout in a given time, suppose a minute, and multiplying the same by the minutes in an hour, the whole force or impulse of the river at any given height and known breadth may be ascertained.

Mr. Smeaton has also given tables of the velocities of a wheel with different heights of water; and from the whole deduces the following conclusions:

1. The virtual or effective head, that is head due to Machinery the velocity being the same, the effect will be nearly as the quantity of water expended.

2. The expense of water being the same, the effect will be nearly as the height of the virtual or effective head.

3. The quantity of water expended being the same, the effect will be nearly as the square of the velocity.

4. The aperture being the same, the effect will be nearly as the cube of the velocity of the water. Hence if the water passes out of an aperture in the same section, but with different velocities, the expense will be proportional to the velocity; and therefore if the expense be not proportional to the velocity, the section of the water is not the same.

5. The virtual head, or that from which we are to calculate the effect, however, bears no proportion to the head of water, but when the aperture is larger, or the velocity of the water less, they approach nearer to a coincidence, and consequently in the large openings of mill sluices, where great quantities of water are discharged from moderate heads, the head of water, and virtual head, determined from the velocity, will nearly agree; which is also confirmed by experience.

6. The most general proportion betwixt the power and the effect is that of 10 to 3; the extremes being 10 to 3.2, and 10 to 2.8. But it is observable, that where the power is greatest, the second term of the ratio is greatest also. Hence we may allow the proportion subsisting in great works to be 3 to 1.

7. The proportion of velocity between the water and the wheel is in general about 5 to 2.

8. There is no certain ratio between the load that a wheel will carry at its maximum, and what will totally stop it, though the proportions are contained within the limits of 20 to 10 and 20 to 15; but as the effect approaches nearest to the ratio of 20 to 15, or of 4 to 3, when the power is greatest, either by increase of velocity or quantity of water, this seems to be the most applicable to large works. But as the load that a wheel ought to have in order to work to the best advantage, can be assigned by knowing the effect that it ought to produce, and the velocity it ought to have in producing it, the exact knowledge of the greatest load is not a matter of much practical importance.

(117.) *Description of the figures.*—Pl. vii. figs. 1, 2, are Pl. vii. a front and side elevation of an iron overshot wheel; in Figs. 1, 2, 3, fig. 1, *pp* is the *pentrough* for conducting on the water; 4, 5, &c. *s* the *shuttle* for regulating the supply, which is drawn backward or forward by the lever *l* and the screw *m*. In fig. 2, *bb* is the principal bevel wheel which drives the Machinery; fig. 3 shows the section of the buckets enlarged and constructed according to the description. (Art. 106.)

Fig. 4 and 5 are the plan and elevation of an iron breast wheel, showing the *sluice s*, which works in grooves in the wall, and is elevated or depressed by means of a ratchet and pinion *r* and *p*, which is turned by the handle *h*, seen in fig. 4, and works inside the mill. In the same figure is seen the principal spur wheel *ww*, which drives the Machinery.

Fig. 6 and 7 are the elevation and plan of an undershot wheel, constructed according to a plan recommended by Smeaton. *s, s* is the sluice, or penstock, which is raised and depressed by the ratchet and pinion *r, p*; in fig. 7 is seen the principal spur wheel *ww*, resting on its bearings *b*.

We have in the above article confined ourselves

Manufac-
tures.

to a description of such water wheels as are in more general use; other forms, however, have been proposed, and partially adopted, one or two of which it may be well to refer to. Of these we have one (an undershot wheel) described in the *Transactions of the Society of Arts*, vol. xix., by Mr. Besant of Brompton; and in 1819 a patent was granted to Mr. Lambert for a wheel of peculiar construction, in which the paddles or floats always preserve a vertical position, in order to avoid the loss supposed to be sustained by the reaction of the water on the rising side of the wheel, or, as it is termed, the back water. A variety of attempts of this kind have been made, since the invention of steam-boats, for their paddles, but generally they have failed from the number of moving parts, which necessarily create a great additional expense, and a want of that firmness and strength so essential in all water wheels, and more particularly in those attached to steam-vessels. Lambert's water wheel is described in Nicholson's *Practical Mechanic*.

Several other improvements connected with water-mills and water wheels have been proposed and acted upon; but generally they have not so much a reference to their figure and construction as to the means employed to regulate the supply of water and other particulars, which, according to the arrangement adopted in this Treatise, will fall under a subsequent Article. One Machine, however, which although not a water wheel, resembles it in some particulars, and is therefore generally classed amongst them, must be described in this place; this is the inverted chain pump, or

Chain of
buckets.
Pl. viii.
Fig. 8.

(118.) *Chain of buckets.*—This Machine and its action are very easily understood. It is represented in PP, fig. 8, where C, D, G, H, &c. are a number of buckets, united by an endless chain, which passes over two wheels A and B, the upper one being on the axle which is to communicate motion to the mill-work. E being the spout to supply the water to the buckets, and by the preponderance of which on one side motion is produced. The principal advantage of this form of water-mill, if we may be allowed so to denominate it, is that no water is lost by running out of the buckets before they arrive at the lowest part, as is the case with the usual overshot wheel; another is, that the buckets being suspended over a wheel of small diameter, it may be made to revolve more quickly than a wheel of larger diameter, and without increasing the velocity of the descending buckets beyond what is proper for them. This saves wheel work when the Machine is to be employed in work requiring a rapid motion; but, on the other hand, the friction of the chain over the wheel at the top will be very considerable, as it must be made to embrace cogs on its circumference. This is, of course, a disadvantage, yet there are many cases in which such an arrangement would be attended with advantage and convenience.

Pen-
troughs,
penstocks,
&c.

(119.) *Of the different methods of supplying water wheels with water.*—In plate vii. exhibiting the figure and action of water wheels, we have also represented the pentroughs, shuttles, and sluices, sufficiently in detail to give the reader a general idea of the means employed for feeding the mill with water, and regulating the supply. This is, however, a matter of some importance, and requires a little further explanation by means of figures more at large.

Fig. 6.

A method of supplying an overshot wheel, and which is very commonly employed in some Counties, is represented in pl. viii. fig. 6. The water here is let on a little

below the upper part, but may be varied to different heights according to circumstances. In most other methods, if the water is subject to variations in height, which is very commonly the case, the wheel must be adjusted to the lowest head, which is unquestionably a disadvantage, whereas in this the water may vary very considerably, and the whole effect of the water be obtained throughout.

Machinery.

Here A A is the pentrough made of cast iron, the end of which is formed by a grating of broad iron bars; these are inclined in a proper position to direct the water through them into the buckets of the wheel. The spaces between the bars are shut up by a large sheet of leather, which is made fast to the bottom of the iron trough as *a*, and is applied against the bars, the pressure of the water keeping it close in contact with them, so as to prevent leakage. This leather is the shuttle, and by opening it the water is let on. The upper edge of the leather is wrapped round a small roller *b*; the pivots at the ends of this roller are received in the lower ends of two racks, which are made to slide up and down, by the action of two pinions fixed upon the same common axle, which extends across the trough, this axle being turned, raises up and lowers down the roller; and the leather shuttle winds upon it as it descends, or unwinds from it as it ascends, so as to open more of the spaces between the bars, or close them, as may be required. In order to make the roller take up the leather, and always draw it tight, a strap of leather is wound round the extreme ends of the roller, beyond the part where the lower shuttle rolls upon it; these straps are carried above water, and applied on wheels which wind them up with a very considerable tension by the action of a band and weight as shown in the figure.

The water runs over the upper side of the roller through spaces between the bars of the grating into the buckets of the wheel, the descent of the water passing through the bars, and afterwards in falling before it strikes the bottom of the bucket, is found fully sufficient to produce the necessary velocity of the water.

For other pentroughs, penstocks, &c. the reader may consult Gregory's *Treatise of Mechanics*, the *Transactions of the Society of Arts*, vol. xi., and several volumes of the *Repertory of Arts*.

(120.) *Tide-mill* is a particular description of water-mill, worked by the ebbing and flowing of the tide, and which, in consequence of the variable head of water, requires some arrangements in its sluices, &c. different from those above described. Before the invention of the steam engine great ingenuity had been displayed in providing mills for grinding corn by the force of water; and as water-mills on rivers are always considered injurious to the agricultural interests, and form a total impediment to inland navigation, recourse has been had to tide-mills on the side of tide rivers and the mouths of harbours.

It is said that the Romans, so early as the Vth or VIth Century, had constructed tide-mills on the Tiber and other rivers; but if so, all traces of them seem to have been lost, and generally the French are considered to have been the inventors of the modern tide-mill, of which there are various kinds. 1st, those in which the water wheel turns one way when the tide is rising, and the other when it is falling; 2dly, those in which the wheel turns in the same direction in both cases; 3dly, those in which the wheel falls or rises as the tide ebbs or flows; and 4thly, those in which the axle of the water wheel is so fixed, that it shall neither rise nor fall,

the rotary motion being still given to the wheel whether it be partially or wholly immersed in the fluid. One of the finest tide-mills in this Country is that erected on the side of the Thames at East Greenwich, the construction of which is such, that the water wheel rises and falls with the tide. We are indebted to Dr. Gregory's *Mechanics* for the description of this ingenious specimen of mill-work.

This mill is intended for grinding corn, and is competent to drive eight pair of stones. The side of the mill house parallel to the course of the river measures 40 feet within; and as the whole of this may be opened to the river by sluice gates, which are carried down to the low-water mark, there is a 40 feet water way to the mill; through this water way the water passes during the rising tide into a large reservoir, which occupies about four acres of land; and beyond this reservoir is a smaller one, in which water is kept, for the purpose of being let out occasionally at low water to cleanse the whole works from mud and sediment, which would otherwise in time clog the Machinery. The water wheel has its axle in a position parallel to the side of the river, that is, parallel to the sluice gates which admit water from the river: the length of this wheel is twenty-six feet, its diameter eleven feet, and its number of float boards thirty-two. These boards do not each run on one plane from one end of the wheel to the other, but the whole length of the wheel is divided into four equal portions, and the parts of the float boards belonging to each of these portions fall gradually one lower than another, each by one-fourth of the distance from one board to another, measuring on the circumference of the wheel. This contrivance is intended to equalize the action of the water upon the wheel, and prevent its moving by jerks. The wheel with its incumbent apparatus weighs about twenty tons, the whole of which is raised by the impulse of the flowing tide when admitted through the sluice gates. It is placed in the middle of the water way, leaving a passage on each side of about six feet for the water to flow into the reservoir, besides that which in its motion turns the wheel round. Soon after the tide has risen to the highest, (which at this mill is often 20 feet above the low-water mark,) the water is permitted to run back again from the reservoir into the river; and by this means it gives a rotary motion to the water wheel, in a contrary direction to that with which it moved when impelled by the rising tide. The contrivance by which the wheel is raised and depressed, and that by which the whole interior motions of the mill are preserved in the same direction, although that in which the water wheel moves is changed, are very ingenious, and require a distinct description. Let *AB* (pl. viii. fig. 2) be a section of the water wheel, *a'*, *b'*, *c'*, *d'*, *e'*, &c. its floats, *CD* the first cog wheel upon the same axis as the water wheel; the vertical shaft *PE* carries the two equal wallower wheels *E* and *F*, which are so situated on the shaft that one or other of them may, as occasion requires, be driven by the first wheel *CD*; and thus (by what has been said under the article *Reversion of motion*) the first wheel acting upon *F* and *E* at points diametrically opposite, will, although its own motion is reversed, communicate the rotary motion to the vertical shaft always in the same direction. In the figure the wheel *E* is shown in gear, while *F* is clear of the cog wheel *CD*; and at the turn of the tide the wheel *F* is let into gear, and *E* is thrown out; this is effected by the lever *G*, whose fulcrum is at *H*, the other

end being suspended by the rack *K*, which has hold of the pinion *L* on the same axle as the wheel *M*; into this wheel plays the pinion *N*; and the winch *O* on the other end of the axle furnishes sufficient advantage to enable a man to elevate or depress the wallower wheels as required. The action of the lever may be shown more clearly by (fig. 3,) where *ab* is a section of the lever, which is formed of two strong bars of iron, as *ab*; there are two steel studs or pins which work in the grooves of the grooved wheel *I*, and this wheel being fixed on the four rods surrounding the shafts, of which three only can be shown in the figures, as *cde*; the ends of these are screwed fast by bolts to the sockets of the wallower wheels, and they are nicely fitted on the vertical shaft, so as to slide with little friction; thus the wallowers may be raised or lowered upon the upright shaft, while the gudgeon on which it turns retains the same position. When the top wallower is in gear, it rests on a shoulder that prevents it from going too far down; and when the bottom one is in gear, there is a bolt that goes through the top wheel socket and shaft, which takes the weight from the level *c*, at the same time that it prevents much friction on the stud or pins of the lever which works in the grooved wheel *I*.

When the tide is flowing, after the mill has stopped a sufficient time to gain a moderate head of water, the fluid is suffered to enter and fall upon the wheel at the sluice *Q*, (fig. 2,) and the tail water to run out at *R*. The hydrostatic pressure of the head of water acting against the bottom of the wheel frame *S*, and at the same time acting between the folding gates *TW*, which are thus converted into very large hydrostatic bellows, buoys up the wheel and frame, (though weighing, as before observed, nearly twenty tons,) and makes them gradually to rise higher and higher, so that the wheel is never, as the workmen express it, *drowned* in the flowing water; nor can the water escape under the wheel frame, being prevented by the folding gates, which pass from one end to the other of the wheel. In this way the wheel and frame are buoyed up by a head of four feet, and the mill works with a head of five or five feet and a half.

When the tide is ebbing, and the water from the reservoir running back again into the river, it might, perhaps, be expected that, in consequence of the gradual subsiding of the water, the water wheel would as gradually lower; but lest any of the water confined between the wheel frame at *S* and the folding gates *TW* should prevent this, there are strong rack-works of cast-iron by which the wheel frame can be either suspended at any altitude, or gradually let down, so as to give the water returning from the reservoir an advantageous head upon the wheel; then the sluice *R* is shut, and *V* opened as well as *X*, the water entering at *X* to act upon the wheel, and flowing out at *R*. The upper surface of the wheel frame is quadrangular, and at each angle is a strong cast-iron bar, which slides up and down in a proper groove, which admits of this vertical motion, but prevents all such lateral deviation as might be occasioned by the impulsion of the stream.

At each end of the water wheel there is a vertical shaft with wallowers, and a first cog wheel, as *F*, *E*, and *CD*; and each of these vertical shafts turns a large horizontal wheel at a suitable distance above the wallowers, while each horizontal wheel drives four equal pinions, placed at equal or quadrantal distances on its periphery, each pinion having a vertical spindle, on the

Manu-
factures.

upper part of which the upper millstone of its respective pair is fixed; other wheels driven by one or other of these pinions giving motion to the bolting and dressing Machines, and different subordinate parts of the mill, which, however, as we are not describing the interior works, do not belong to this article.

The vertical shaft at each end of the water wheel rises and falls, as we have already stated, with that wheel, but the large horizontal wheel turning with the shaft, and which drives the Machinery, does not rise and fall, but remains always in the same horizontal plane, and in contact with the four pinions it drives. The contrivance for this purpose is very simple, but very efficacious; each great horizontal wheel has a nave, which runs upon friction rollers, and has a square aperture passing through it vertically, just large enough to allow the shaft to slide freely up and down in it, but not to turn round without communicating its rotary motion to the wheel; thus the weight of the wheel causes it to press upon the friction rollers, and retain the same horizontal plane, and the action of the angles of the vertical shaft upon the corresponding parts of the square orifice in the nave, causes it to partake of the rotary motion, such motion being always in one direction in consequence of the contrivance by which one or other of the wallowers E F is brought into contact with the opposite points of the first cog wheel, C D.

In the above case the wheel rises with the tide, but it has been stated, that some tide wheels remain fixed in their place, and revolve even when nearly immersed in the water. Belidor describes a mill of this kind, which works when completely immersed; but a more recent and simple construction is that invented by Mr. Dryden, although it will not bear so much immersion as the former. This is represented in fig. 4. which is an elevation of it, its upper part being supposed to stand a foot or too higher than the tide ever rises; the axis of this wheel remains always in one place, and the wheel work at high water when the head is at B and the tail water at the dotted line A; it will also perform nearly the same work when the head is at C, and the tail water level with the bottom of the wheel. The floats are all set at one and the same angle with the respective radii of the wheel, as may be seen in the figure, and are made so as to have an opening of at least an inch between each float, and the drum boarding or soling of the wheel. This opening is intended to prevent the wheel from being impeded by the tail water, for by this means, as the bucket rises out of the water, there can be no vacuum formed in it, there being a full supply of air, in consequence of which the water leaves the wheel freely. The case is different with regard to wheels made in the common way; for if such are open wheels, the floats are made in such a manner as to go through the tail water if they are immersed any depth in it; or, if they are close, the wheel wants proper vent for the air to prevent the formation of a vacuum in the rising buckets, or, what is called by the miller "sucking up the tail water." At D is planking made circular to fit the wheel pretty close for rather more than the space of two floats, so as to confine the water nearly close to the wheel. E, F, G, H are sluices which are all connected together by the iron bar I, and are lifted with the assistance of a wheel, two pinions, and a winch, the first pinion working into the rack K; these sluices are merely for stopping the wheel when occasion requires, although one might be sufficient to

Fig. 4.

supply the wheel. The rings of this wheel may be made either of cast-iron or of wood; the floats may be iron plates riveted together. The flanches on the arms of the wheel, exhibited in the figure, are intended to facilitate the fixings of the first cog wheel; the ring of the wheel may be fixed to the flanches at the extremity of the arms, and the large flanch made fast to the axle will receive the middle part of the wheel. See Gregory's *Mechanics*.

It still remains for us to describe another engine, worked by water, and employed in some few cases to drive Machinery, but more commonly for grinding, and which is generally dignified by the term mill; that is the

(121.) *Recoil mill* or *Barker's mill*, the former name being derived from its mode of action, and the other from the name of its projector. This Machine is represented as being employed in grinding corn in fig. 5, where A is a pipe or channel which brings water from the reservoir to the upright tube. The water runs down the tube, and thence into the horizontal trunk C, which has equal arms; and, lastly, runs out through holes at d and e, opening on contrary sides near the ends of those arms. These orifices, d, e, have sliders fitted to them, so that their magnitude may be increased or diminished at pleasure.

The upright spindle D is fixed in the bottom of the trunk, and screwed to it below the nut g, and is fixed into the trunk by two cross bars at f; so that, if the tube B and trunk C be turned round, the spindle D will be turned also. The top of the spindle, when the mill is employed for grinding, goes square into the rynd of the upper mill-stone, as in common mills; and, as the trunk, tube, and spindle turn round, the mill-stone is turned round likewise. The lower or quiescent millstone is immediately above the floor K, on which it rests, and in which is the hole to let the meal run through, and fall down into a trough which may be about M. The hoop or case that goes round the millstone rests on the floor K, and supports the hopper in the common way. The lower end of the spindle turns in a hole in the bridge tree G F, which supports the millstone, tube, spindle, and trunk. This tree is movable on a pin at h, and its other end is supported by an iron rod N fixed to it, the top of the rod going through the first bracket O, and having a screw-nut upon it, above the bracket. By turning this nut forward or backward, the millstone is raised or lowered at pleasure. We here suppose the mill employed in grinding, in other cases a wheel may supply the place of the revolving stone. While the tube B is kept full of water from the pipe A, and the water continues to run out from the ends of the trunk, the upper millstone H, together with the trunk, tube, and spindle, turn round; but if the holes in the trunk were stopped, no motion would ensue, even though the tube and trunk were full of water; for, if there were no holes in the trunk, the pressure of the water would be equal against all parts of its sides within.

But when the water has free egress through the holes, its pressure there is entirely removed, and the pressure against the parts of the sides which are opposite to the holes turns the Machine. M. Mathon de la Cour, in 1775, made an improvement in this Machine, by conveying the water from the reservoir, not by a pipe as A D B, in great part of which the spindle turns, but by one which descends from A without the frame L N, till it

Machinery.

Barker's
mill.
Fig. 5.

reaches as low, or lower than G; whence it is conveyed by a curvilinear neck and collar to g, where it enters the arms, as is shown by the dotted lines at the lower part of the figure; a like improvement was made by M. Segner, a German, and afterwards by Ramsay, an American.

The theory of this engine is but little understood, its action and efficiency being very differently stated by different authors. The following appears to us to be decidedly more intelligible, more simple, and more correct than any hitherto given. It is due to Davies Gilbert, Esq., late President of the Royal Society, whose scientific and mechanical knowledge is well known and duly appreciated by the public as well as by the writer of this article. Mr. Gilbert, of course, decides against the mechanical advantage of the Machine, which is, indeed, tacitly admitted by the little use made of it; at the same time it will not be uninteresting to state the grounds of its inefficiency, as, even within a very few years, its merits were supported by some members of a highly useful and respectable society in the Metropolis.

Let every thing be taken in the abstract, and after a manner most advantageous to the Machine. Suppose friction to vanish, and that the perpendicular tube and the arms are so capacious as to allow of the fluid issuing with a velocity equal to what a body would acquire by falling in free space, through an elevation equal to that of the perpendicular tube, or through, what is usually termed, the head. See *Principia*, book ii. sec. 7.

Let l = the space in English feet through which a body freely descends in one second of time.

Then $2l$ = the velocity acquired.

h = the length of the perpendicular tube, or the actual height of the head.

Then $2\sqrt{hl}$ = the velocity due to the head.

Let R = the length of either arm from the centre to the orifice.

= the velocity with which that point moves in revolving, expressed by feet in a second.

Then $\frac{x^2}{2lR}$ = the centrifuga. force at the orifice.

And since the force exerted by each particle of the fluid varies as its distance from the centre,

$\frac{x^2}{2lR} \times \frac{R}{2} = \frac{x^2}{4l}$ = the whole pressure from centrifugal force. An expression independent of the length of the arm; and the slightest reflection will make it appear that no alteration can arise from deflecting the form of the arm out of a straight line. Then, since the pressure exerted by the actual head is expressed by its height h , and the pressure from the centrifugal force by $\frac{x^2}{4l}$

$h + \frac{x^2}{4l}$ = the pressure sustained, or the virtual head,

and $\left(h + \frac{x^2}{4l}\right) \times x$ = the efficiency applied to the Machine, in relation, however, not to the expenditure of fluid corresponding to the height h , but to an expenditure

greater in the proportion of $\sqrt{1 + \frac{x^2}{4hl}}$ to 1. But

a portion of this efficiency must, of necessity, be expended in giving the rotary velocity (x) to the quantity

VOL. VII.

of fluid issuing = $\sqrt{1 + \frac{x^2}{4hl}}$. Now the height due Machinery.

to x is $\frac{x^2}{4l}$, consequently $\sqrt{1 + \frac{x^2}{4hl}} \times \frac{x^2}{4l} \times x$ = the expenditure of efficiency in producing the rotary motion;

and $\left(h + \frac{x^2}{4l} - \sqrt{1 + \frac{x^2}{4hl}} \times \frac{x^2}{4l}\right) \times x$ = the efficiency applied to the Machine capable of producing duty.

Now substitute for x the velocity due to h , ($2\sqrt{hl}$)

multiplied by an arbitrary quantity y ; then $\sqrt{1 + \frac{x^2}{4hl}}$

(or the quantity of fluid issuing) = $\sqrt{1 + y^2}$, and

$2h^{\frac{3}{2}}l^{\frac{1}{2}}\{(1 + y^2)y - y^3\sqrt{1 + y^2}\}$ = efficiency, and dividing by $\sqrt{1 + y^2}$

$2h^{\frac{3}{2}}l^{\frac{1}{2}}\{y\sqrt{1 + y^2} - y^3\}$ =

the efficiency that would be applied if no more fluid issued than what is due to the actual head (h .)

The following Table exhibits the value of both these functions, taking (y) from 0, (where the duty must obviously be nothing,) by steps of $\frac{1}{10}$ ths, to 1.25; after which the duty becomes negative.

y	The Duty for a given Expenditure of Fluid on the Function $y\sqrt{1+y^2}-y^3$.	y	The Duty performed actually by the Expenditure of Fluid on the Function $y+y^2-y^3\sqrt{1+y^2}$.
.05	.04994	.05	.05000
.10	.09950	.10	.10000
.15	.14830	.15	.14997
.20	.19596	.20	.19984
.25	.24247	.25	.24952
.30	.28621	.30	.29981
.35	.32794	.35	.34762
.40	.36681	.40	.38607
.45	.40234	.45	.41159
.50	.43402	.50	.48525
.55	.46132	.55	.52649
.60	.48371	.60	.56410
.65	.50062	.65	.59706
.70	.51146	.70	.62432
.75	.51563	.75	.64454
.80	.51250	.80	.65632
.85	.50145	.85	.65812
.90	.48183	.90	.64824
.95	.45297	.95	.62476
1.00	.41421	1.00	.58578
1.05	.36488	1.05	.52908
1.10	.30427	1.10	.45233
1.15	.23170	1.15	.35311
1.20	.14646	1.20	.22878
1.25	.04785	1.25	.07660
1.28	.01803	1.28	.02929
	Negative.		Negative.

The first of these functions reaches the maximum, when y exceeds .75 or $\frac{3}{4}$ by two or three thousandths, and the second when y is about .83.

From an inspection of the Table, it appears, that when the Machine is moving with the velocity productive of its greatest relative effect, namely, at three quarter parts of the velocity with which the fluid would issue under a pressure equal to that of the actual head, that the duty exceeds by a mere trifle one half of the efficiency expended; and from thence it obviously follows, that the recoil engine cannot in any case be employed with

Manufac-
tures.

advantage. The water wheel, whenever the fall does not exceed forty or fifty feet, and the pressure engine, provided with an air vessel, in all cases where the fall is greater, receive an efficiency almost equal to the whole expended, instead of one half; and in practice, the duty will reach three quarters. The wheel, moreover, possesses a self-regulating power, sufficiently accurate for the present illustration, and somewhat analogous to the isochronism of the pendulum; that is, the actual weight of water on the wheel, and its velocity of rotation, must always be reciprocal to each other; thus maintaining a given efficiency, independent of velocity. The received efficiency of a water wheel being represented by the power of water passing over it, multiplied by the fall in feet, minus the height due to the velocity with which the periphery moves in its rotation. But in the recoil engine, the moving power is expending at the rate due to the height even when the Machine is actually standing still; and when it moves with a velocity exceeding that due to the length of the head, in the proportion of about 128:1, (where the duty is again nothing,) the moving power will be expended at the increased rate $\sqrt{1 + (1.28)^2} : 1$.

Hence too may be easily shown the utter impossibility of executing a plan, which would not, indeed, deserve any notice, were it not that two ingenious practical engineers have within these few years, although at different times, and independently of each other, incurred large expense, and employed much pains in attempting to apply steam on the principle of recoil. *Phil. Trans.* 1827.

Authors on
mills and
mill work.

(122.) The following list of authors who have written on the subject of mills may be both useful and instructive to the general reader. We are indebted for it to Dr. Gregory's *Mechanics*.

Künstliche Abriss, allerhand Wasser-Wind-Ross- und Hand-Mühlen, &c. Von Jacob. de Strada, à Rosberg, 1617.

Georg. Christoph. Luerner, *Machina torrentica nova; oder, Beschreibung der neu erfundenen Drehmühlen*, 1661.

Theatrum Machinarum Novum; das ist, neu vermehrter Schauplatz der mechanischen Künste handelt von allerhand Wasser-Wind-Rossgewicht- und Hand-Mühlen. Von Geo. And. Bocklern, 1661.

Contenta discursus Mechanica, concernentis Descriptionem optimæ formæ Velorum Horizontalium pro usu Molarum, necnon fundamentum inclinorum Velorum in Navibus; habita coram Societate Regia à R. H. translata ex collectionibus philosophicis M. Decum, 3. p. 61. 1681.

Dissertatio Historica de Molis quam præside Joh. Phil. Treuer, defend. Joh. Tob. Mühlberger, Ratisbonens, Jenæ, 1695.

Martin Marten, *Wiskundige beschonwinge der Wind of Wadermoolens, vergeleken met die van den heer Johann. Lulofs*, Amsterdam, 1700.

Vollständige Mühlen-baukunst, von Leonhard Christoph. Sturm, 1718.

Jacob Leupold, *Theatrum Machinarum*, 1724, 1725.

Remarques sur les Aubes ou Pallettes des Moulins, et autres Machines mues par le Courant des Rivières. Par M. Pitot, Mem. Acad. Roy. Paris, 1729.

Job. van Zyl, *Theatrum Machinarum Universale of groot algemeen moolen bock, &c.* Amsterdam, 1734.

Jo. Caral. Totens, *Disser. de Machinis Molaribus optimè construendis*, Lugd. Batav. 1734.

Kurze aber deutliche Anweisung zur Construction der Wind- und Wasser-Mühlen, von Gottfr. Kinderling, 1735.

Desaguliers, *Experimental Philosophy*, 1735, 1744. *Architect. re Hydraulique*, par M. Belidor, 1737, 1753.

Part of a Letter from Mr. W. Anderson, F. R. S., to Mr. Baker, F. R. S., containing a Description of a Water Wheel for Mills invented by Mr. Philip Williams. *Phil. Trans.* vol. xlv. 1746.

Leonh. Euleri *De Constructione aptissimâ Molarum Alatarum*, Disp. Nov. Com. Acad. Petrop. tom. iv. 1752.

Mémoire dans lequel on démontre que l'Eau d'une Châte destinée à faire mouvoir quelque Machine, Moulin ou autre, peut toujours produire beaucoup plus d'effet en agissant par son poids qu'en agissant par son choc, et que les roues à pots qui tournent lentement produisent plus d'effet que celles qui tournent vite, relativement aux Châtes et aux Dépenses. Par M. de Parcieux, Acad. Roy. Paris, 1754.

Jo. Alberti Euleri *Enodatio Questionis: Quo modo Vis Aquæ aliussve Fluidi cum maximo lucro ad Molas circumagenda, aliave Opera perficienda impendi possit?* Præmio à Societate Regia. Sci. Gotting. 1754.

Recherches plus exactes sur l'Effet des Moulins à vent, par M. Euler, Hist. Acad. Roy. Berlin, 1756.

An Experimental Inquiry concerning the natural Powers of Wind and Water-mills, and other Machines depending on a circular Motion. By J. Smeaton, F. R. S. *Phil. Trans.* 1759.

Abstracts of this and Mr. Smeaton's other Papers on Water and Wind-mills, are given in this Treatise and in our Article HYDROSTATICS. They were collected and published by Taylor, Holborn, in 1794.

Mémoires dans lequel on prouve que les Aubes des Roues mues par les Courans des grandes Rivières feroient beaucoup plus d'effet si elles étoient inclinées aux Rayons qu'elles ne font étant appliquées contre les Rayons mêmes, comme elles le sont aux Moulins pendans et aux Moulins sur bateaux qui sont aux Rivières de Seine, de Marne, de Loire, &c. Par M. de Parcieux, Mem. Acad. Roy. Paris, 1759.

Joh. Albert Euler, *Abhandlung von der Bewegung ebener Flächen wenn sie vom Winde getrieben werden* 1765.

Schauplatz des mechanischen Mühlenbaues, darinnen von verschiedenen Hand-Trett-Rossgewicht-Wasser- und Wind-Mühlen gehandelt wird, durch Johann. Georg. Scopp. I. C. iter theil, 1766.

Theatrum Machinarium Molarium, oder Schauplatz der Mühlenbaukunst, als der neunte Theil von dessel. von Jac. Leupolds Theatro Machinarum, von Joh. Mathais, Beyern, 1767, 1788, 1802.

A Memoir concerning the most advantageous Construction of Water-wheels, &c. by Mr. Mallet of Geneva, *Phil. Trans.* 1767.

Mémoire sur les Roues Hydrauliques, par M. le Chevalier de Borde, Mem. Acad. Roy. Paris, 1767.

Kurzer Unterricht allerley Arten von Wind- und Wasser-Mühlen auf die vortheilhafteste Weise zu erbauen, nebst einigen Gedanken über die Verbesserung des Räderwerks an den Mühlen, von Joh. König, 1767.

G. G. Bischoff, *Beyträge zur Mathesis der Mühlen*, 1767.

Sur la Position des Ailes des Moulins à vent, D'Alembert, *Opusc. Mathema.* tom. v. 1768.

Manufac-
tures.

Détermination générale de l'Effet des Roues mues par le Choc de l'Eau, par M. l'Abbé Bossut, Mem. Acad. Roy. Paris, 1769.

Andreas Kaovenhöfer, *Deutliche Abhandlung von den Rädern der Wassermühlen, und von dem Einrändigen Werke der Schneidemühlen*, 1770.

Manuel du Meunier et du Charpentier des Moulins, rédigé par Edm. Bequillet, 1775.

Remarques sur les Moulins à Vent, par M. Lambert.

Remarques sur les Moulins et autres Machines où l'Eau tombe en dessus de la Roue, par M. Lambert.

Expériences et Remarques sur les Moulins que l'Eau meut par en bas dans une Direction Horizontale, par M. Lambert.

Remarques sur les Moulins et autres Machines dont les Roues prennent l'Eau à une certaine hauteur, par M. Lambert.

(The last four articles are inserted in *Mém. Acad. Roy. Berlin*, 1775.)

Of the Degrees and Qualities of Winds requisite to move the heavier kinds of Wind Machines, by John Stedmann, M.D. *Phil. Trans.* 1777.

Ausführliche Erklärung der Vorschläge für die längere Dauer der Mühlenwerke, nebst ähnlichen Gegenständen, in ein Gespräch verfasset, von Johann Christian Füllmann, Mühlenmeister, 1780.

Observations Théoriques et Expérimentales sur l'Effet des Moulins à Vent, et sur la Figure de leurs Ailes, par M. Coulomb, Mem. Acad. Roy. Paris, 1781.

Tratado de los Granos y Modo de Molerlos con Economía de la Conservacion de Astos y de las Harinas; escr. en Fr. par M. Bequillet, y extract. y trad. al Cast. con algun Notas y un Supplem., por Ph. Marescaulchi, Madrid, 1786.

Suite de l'Architecture Hydraulique, par M. Fabre, 1786.

Mémoires sur les Moyens de perfectionner les Moulins, et la Mouture Economique, par C. Bricquet, 1786.

Manuel, ou Vocabulaire des Moulins à pot, à Amst. 1786.

Die nothigsten Kenntnisse zur Anlegung, Beurtheilung und Berechnung der Wassermühlen, und zwar der Mahl-Oehl- und Säge-Mühlen, für Anfänger und Liebhaber der Mühlenbaukunst, von Joh. Christ. Huth, 1787.

An Essay proving Iron far superior to Stone of any kind for breaking and grinding Corn, &c. by W. Walton, 1788.

Mühlenpraktik, oder Unterricht in dem mahlen der Brodfrüchte für polizey beamte, Verksleute und Hauswirthe, von L. Ph. Hahn, 1790.

The Young Millwright and Miller's Guide, by Oliver Evans, Philadelphia, 1790.

Manuel du Meunier et du Constructeur des Moulins à Eau et à Grains, par C. Bricquet, 1791.

Praktische Anweisung zum Mühlenbau, von Lr. Clausen, 1792.

Beschreibung zwei Maschinen zur Reinigung des Korns, von Lr. Clausen, 1792.

Instructions sur l'Usage des Moulins à Bras, inventés et perfectionnés par les Citoyens Durand, père et fils, Mécaniciens, 1793.

Theoretisch-praktische Abhandlung über die Besserung der Mühräder von dem Verfasser der zweckmässigen Lustreiniger, &c. 1795.

A Treatise on Mills, in four Parts, by John Banks, 1795.

Handbuch der Maschinenlehre, für Praktiker und

Akademische Lehrer, von Karl Christian Langsdorf, Machinery. 1797, 1799.

On the Power of Machines, including Barker's Mill, Westgarth's Engine, Cooper's Mill, Horizontal Water wheel, &c. by John Banks, 1803.

The Experienced Millwright, by Andrew Gray, Millwright, 1804.

To these we may add also,

A Sketch of the Properties and Advantages of Sutton's Patent Gravitated Sails for Windmills, by W. Smith, Hesleden, 1807.

Four Essays on Practical Mechanics; the first on Water-wheels, the second on the Steam Engine, the third on Mills, and the fourth on the Simplification of Machinery, by Thomas Fenwick, 1801.

The Transactions of the Society of Arts, &c. several volumes of which contain many ingenious improvements in mill work. See also the *Repertory of Arts*, in several volumes of which are described various patented inventions on the same subjects.

OF THE STEAM ENGINE, AND ITS APPLICATION TO MINING, NAVIGATION, &c.

(123.) Before attempting any illustration of the mechanical operations of this important engine, it will be necessary to establish the laws of the great agent of all its action, STEAM. It is only after having fully understood the nature of this elastic fluid or vapour, the laws which appertain to its generation and condensation, its increase or decrease of elasticity, resulting from and depending upon an increase or decrease of temperature, that we can appreciate the value of the many ingenious and important changes, not only in form but in principle, which it has undergone since its first rude introduction as an agent of mechanical force. In its primitive state its power was of very limited extent, and its application restricted to one single operation, *pumping*. We have to trace it from this state through various changes, till we find it employed in almost every description of Manufacture, performing the labour in this Country of more than three millions of men, impelling vessels of immense tonnage from port to port, not only along rivers and sea-coasts, but across seas and oceans, with a degree of certainty and security which could never have been contemplated even by the most sanguine of the original projectors of this modern application of its power. On land we find it superseding the use of horses, and doubling the speed of the swiftest of these animals, and thus reducing the time of transit between places which, only a few years back, was the business of a day, to a pleasant and easy ride scarcely exceeding an hour. It will be our business in the following pages to trace and illustrate these extraordinary inventions and improvements; and, in order to preserve their chain of connection as entire as possible, we propose, in the first place, to treat of the power, the generation, and condensation of steam, and the several laws by which its power is regulated; thus separating the chemical and philosophical from the mechanical character of the engine.

Of Steam.

(124.) *Steam* may be defined to be the invisible vapour of water which is given off by it at all known temperatures under certain degrees of pressure.

Manufac-
tures.

This does not agree with the popular idea of steam, according to which it is the visible moist vapour arising from all bodies which contain juices easily expelled from them by heat, not sufficient for their combustion, being distinguishable from smoke by not containing any soot, and by being condensible by cold. This visibility of steam, however, is so far from being an essential characteristic of, that it is altogether foreign to it, and can only have place when it is mixed with or disseminated in air, or in some elastic fluid colder than itself.

Vapour is nearly synonymous with steam; the latter term, however, is commonly limited to express the vapour from water; the former is more general, being applied to any condensible gas.

Heat is a quality diffused through all bodies in nature, and has a constant tendency to an equilibrium; that is, when accumulated in any body, or parts of a body, in greater abundance than in others, the hotter body gives off quickly a portion of its own heat to the surrounding bodies till an equilibrium is established.

Caloric is a term used to express the cause or matter of heat in bodies; its nature is not at all understood, but it is generally, and more simply, treated of as a very subtle, elastic, and imponderable fluid.

Specific heat.—When there is an equilibrium of heat amongst adjoining bodies, and a fresh supply of it is introduced, different bodies will be found to have absorbed different quantities of this supply; when the whole are again in equilibrio, and the peculiar quantity of this additional heat absorbed by each body is denominated the specific heat of that body. Tables of the specific heat of bodies have been formed by different experiments; that of water at 60° of Fahrenheit being commonly assumed as unity.

Capacity of heat is sometimes confounded with the specific heat of bodies; for as one body absorbs more heat than another to raise its temperature a certain number of degrees, it may be said to have a greater capacity for heat: others, however, distinguish between the two terms, by limiting the term *capacity for heat* to the relation between the whole quantity of heat in bodies of the same temperature; and *specific heat* to express, as we have already defined it, the quantity necessary to produce a certain change of temperature. A change of state of bodies is frequently the result of an increase or abstraction of heat. Thus ice by an increase of heat becomes water, and water by an increase of heat becomes vapour or steam; so, conversely, by abstracting heat, steam becomes water, and water ice, and in these different states the same matter has a different capacity for heat. Steam has a greater capacity for heat than water, and water than ice. This difference in the conversion of water into steam is very great. When a given quantity of water heated to 212° is converted into steam of the same temperature, the heat necessary to produce the change would raise the temperature of about five and a half times as much water from the freezing point 32° to the boiling point 212°.

Of the Latent Heat of Steam.

(125.) It appears from the last paragraph that a large quantity of heat is absorbed by the water in a state of steam, which is not evident to our sensations nor to the thermometer: this heat thus absorbed is denominated *latent heat*; it is given out again when the steam is condensed into water.

Experi-
ments on
the latent
heat of
steam.

The heat combined or disengaged by a change of the state of a body, or its latent heat, is measured in the same manner as specific heat, that is, by the quantity of heat necessary to raise the temperature of a certain quantity of water at 60° one degree.

This great absorption of heat in water passing from its liquid into a gaseous form is of course a very important consideration in the economy of the Steam Engine, and was a part to which the talents and ingenuity of Watt were directed very early in his progress of improvement in this important engine. It was no doubt the distinguished Philosopher Dr. Black, who first discovered, or rather, perhaps, he was the first who illustrated that a change in the state of bodies required a certain addition or abstraction of heat; that the quantity is different for different bodies, and also different according to the nature of the change. The importance of this discovery, and the theory of latent heat by which it is explained, are highly important to general science, and have undoubtedly an immediate application to the economy of this engine; but their importance has been perhaps rather overrated, being sometimes represented as forming the groundwork of all its modern improvements. It will be seen, however, by the following quotation from a letter of Mr. Watt to Sir David Brewster, as well as from the nature of the discovery, that this theory, beautiful as it is in itself, was not essential to the applications which Watt made of the power of steam as a propeller of his engine. Dr. Robison seems to have first fallen into this error, in his article Steam Engine in the *Encyclopedia Britannica*, an error which has spread from that source through many other historical sketches of the steam engine, not only in this Country but in France. These at length called forth some remarks from Mr. Watt, not long before his death, addressed to Sir David Brewster, when engaged in a republication of Dr. Robison's Works. See the Introduction to vol. ii. These it will be but justice towards this ingenious mechanician to quote. The subject is undoubtedly intimately connected with the due performance of the steam engine, whose operation depends upon a constant rarefaction of water into steam, and of the condensation of steam into water; still, however, a knowledge of the fact, without any knowledge of the actual theory of its action, was all that was essentially necessary to Mr. Watt; and, therefore, to attribute all his brilliant discoveries to the theory of Dr. Black, is to do him an injustice, and which he thought necessary, at the recommendation of his friends, to remark upon in the Work to which we have referred. These remarks, as above stated, are given in the form of a letter to Sir David Brewster, of which we think it right to give the following extract. After stating the nature of some notes and alterations he had found it necessary to make in Dr. Robison's account relative to the mechanical arrangements of his engine, he says, "Here it was my intention to have closed this Letter; but the representations of friends, whose opinions I highly value, induce me to avail myself of this opportunity of noticing an error into which not only Dr. Robison, but apparently also Dr. Black, has fallen, in relation to the origin of my improvements upon the steam engine, and which, not having been publicly controverted by me, has, I am informed, been adopted by almost every subsequent writer upon the subject of Latent Heat."

"Dr. Robison, in the article Steam Engine, after passing an encomium upon me, dictated by the partiality of friendship, describes me as the 'pupil and intimate friend of

Watt's re-
marks on
the subject
of latent
heat.

Manufactures.

Dr. Black; a description which, not being there accompanied with any inference, did not particularly strike me at the time of its first perusal. He afterwards, in the dedication to me of his edition of Dr. Black's *Lectures upon Chemistry*, goes the length of supposing me to have professed to owe my improvements upon the steam engine, to the instructions and information I had received from that gentleman, which certainly was a misapprehension; as, though I have always felt and acknowledged my obligations to him for the information I had received from his conversation, and particularly for the knowledge of the doctrine of Latent Heat, I never did, nor *could*, consider my improvements as originating in those communications. He is also mistaken in his assertion, page 8 of the preface of the above Work, that 'I had attended two courses of the Doctor's Lectures;' for, unfortunately for me, the necessary avocations of my business prevented me from attending his or any other Lectures at College; and as Dr. Robison was himself absent from Scotland for four years at the period referred to, he must have been misled by erroneous information. In page 184 of the Lectures, Dr. Black says, 'I have the pleasure of thinking that the knowledge we have acquired, concerning the nature of elastic vapours, in consequence of my fortunate observation of what happens in its formation and condensation, has contributed, in no inconsiderable degree, to the public good, by suggesting to my friend Mr. Watt of Birmingham, then of Glasgow, his improvement in this useful engine.' (Meaning the steam engine, of which he is then speaking.) There can be no doubt, from what follows in his description of the engine, and from the very honourable mention which he has made of me in various parts of his Lectures, that he did not mean this to lessen any merit that might attach to me as an inventor, but on the contrary, he was always disposed to give me fully as much praise as I deserved. And were that otherways doubtful, it would, I think, be evident from the following quotation from a Letter of his to me, dated 13th February, 1783, where speaking of an intended publication by a friend of mine, on subjects connected with the history of steam, he says, 'I think it is very proper for you to give him a short account of your discoveries and speculations, and particularly to assert clearly and fully your sole right to the honour of the improvements of the steam engine;' and in a written testimonial which he very kindly gave on the occasion of a trial at law against a piracy of my invention, in 1796—7, after giving a short account of the invention, he adds, 'Mr. Watt was the sole inventor of the capital improvement and contrivance above mentioned.'

"Under this conviction of his candour and friendship, it is very painful to me to controvert any assertion or opinion of my revered friend; yet, in the present case, I find it necessary to say that he appears to me to have fallen into an error; and I hope, in addition to my assertion, to make that appear by the short history I have given of my invention in my notes upon Dr. Robison's Essay, as well as by the following account of the state of my knowledge previous to my receiving any explanation of the doctrine of latent heat, and also from that of the facts which principally guided me in the invention.

"It was known very long before my time, that steam was condensed by coming into contact with cold bodies, and that it communicated heat to them; witness the common still, &c. &c.

"It was known by some experiments of Dr. Cullen

and others that water and other liquids boiled in vacuo at very low heats; water below 100°.

Machinery.

"It was known to some philosophers, that the capacity or equilibrium of heat, as we then called it, was much smaller in mercury and tin than in water.

"It was also known that evaporation caused the cooling of the evaporating liquid, and bodies in contact with it; I had myself made experiments to determine the following facts:—

"1. The capacities for heat of iron, copper, and some sorts of wood, comparatively with water. Similar experiments had also subsequently been made by Dr. Irvine, on these and other metals.

"2. The bulk of steam as compared with that of water.

"3. The quantity of water which could be evaporated in a certain boiler by a pound of coals.

"4. The elasticities of steam of various temperatures greater than that of boiling water, and an approximation to the law which it followed at other temperatures.

"5. How much water in the form of steam was required every stroke by a small Newcomen's engine, with a wooden cylinder six inches in diameter, and twelve inches long in the stroke.

"6. I had measured the quantity of cold water required in every stroke to condense the steam in that cylinder, so as to give it a working power of about seven pounds on the inch.

"Here I was at a loss to understand how so much cold water could be heated so much by so small a quantity in the form of steam, and applied to Dr. Black, as is related in the short history, p. 116. note, and then first understood what was called latent heat.

"But this theory, though useful in determining the quantity of injection necessary where the quantity of water evaporated by the boiler and used by the cylinder was known, and in determining by the quantity and heat of the hot water emitted by Newcomen's engines, the quantity of steam required to work them, did not lead to the improvements I afterwards made in the engine. These improvements proceeded upon the old established fact, that steam was condensed by the contact of cold bodies, and the latter known one, that water boiled in vacuo at heats below 100°, and, consequently, that a vacuum could not be obtained unless the cylinder and its contents were cooled every stroke to below that heat. These, and the degree of knowledge I possessed of the elasticities of steam at various heats, were the principal things it was necessary for me to consider in contriving the new engine. They pointed out that, to avoid useless condensation, the vessel in which the steam acted upon the piston ought always to be as hot as the steam itself; that to obtain a proper degree of exhaustion, the steam must be condensed in a separate vessel, which might be cooled to as low a degree as was necessary without affecting the cylinder; and that as the air and condensed water could not be blown out by the steam, as in Newcomen's, they must be extracted by a pump, or some other contrivance; that, in order to prevent the necessity of using water to keep the piston air tight, and also to prevent the air from cooling the cylinder during the descent of the piston, it was necessary to employ steam to act upon the piston in place of the atmosphere. Lastly, to prevent the cylinders from being cooled by the external air, it was proper to inclose it in a case containing steam; and again to enclose that in a case of wood, or of some other substance which transmitted heat slowly.

Manufac-
tures.

Black's ex-
periments
and deduc-
tions.

"Although Dr. Black's theory of latent heat did not suggest my improvements on the steam engine, yet the knowledge upon various subjects which he was pleased to communicate to me, and the correct modes of reasoning, and of making experiments, of which he set me the example, certainly conduced very much to facilitate the progress of my inventions; and I still remember with respect and gratitude the notice he was pleased to take of me when I very little merited it, and which continued throughout his life.

"To Dr. Robison I am also bound to acknowledge my obligations for very much information and occasional assistance in my pursuits; and, above all, for his friendship, which ended only with his life; a friendship which induced him, when I was beset with a host of foes, to come to London in the depth of Winter, and appear as a witness for me in a Court of Justice, while labouring under an excessively painful disorder, which ultimately deprived him of life. To the remembrance of that friendship is principally owing my taking upon myself the office of his commentator at my advanced age."

It has been thought right to give this rather long extract, as it is very desirable, in a discovery or improvement of such immense national advantage as that attending the modern principle of the steam engine, that the full merit of every step in the progress of the same should be attributed to its proper authors. We must now proceed with our illustrations.

(126.) The additional heat in the vapours or steam of any liquid is not very easily determined; but since the discovery to which we have alluded by Dr. Black, experiments have been made by several Philosophers, distinguished for their accuracy and skill in such researches. Dr. Black's method is simple and easily tried, but it is not sufficiently accurate. When a vessel containing water is placed on a fire, the water gradually becomes hotter till the temperature reaches 212° ; but after that its temperature does not increase, the water is flying off in steam, and the heat not raising the temperature higher, as we know it would do if the vessel were closed, we must conclude that the heat, which would be communicated to the water in a close vessel, combines with the steam in an open one, and yet does not increase the temperature of that steam to more than that of boiling water. To ascertain the quantity of heat which is thus combined with the steam, Dr. Black put some water in a tin plate vessel, upon a piece of red-hot iron. The water was at the temperature of 50° , in four minutes it began to boil, and in twenty minutes it was all evaporated. During the first four minutes it had received $212^{\circ} - 50^{\circ} = 162^{\circ}$ of heat, or $40\frac{1}{2}^{\circ}$ per minute. If we suppose it received the same quantity per minute during the whole process, the whole quantity of heat $40\frac{1}{2}^{\circ} \times 20 = 810^{\circ}$; and this had converted the whole of the water into steam; but it is not indicated by the thermometer, the temperature of this being never more than 212° ; this 810° therefore Dr. Black considered as latent heat. But the result is obviously inaccurate, because steam is formed during the heating of the water to the boiling point, and the vessel is losing heat from its surface in unequal quantities, and the effect of the fire is also unequal, being less as the heat of the water increases. This, however, was but a first attempt at forming an estimate, since which much more accurate methods have been adopted, and a tolerable certain result has been at length obtained.

(127.) Mr. Watt, in 1780, made several experiments on

this subject, which are described by him in the article we have already quoted, and from the result of those on which he could place the most reliance, he obtained 950° for the additional heat in the steam of water. These experiments were made by condensing steam into water, and measuring accurately the increase of temperature produced by the absorption of the latent heat of the steam; and in a similar way experiments were made by Count Rumford, Mr. Southern, and, more lately, by Dr. Ure.

In 1803, Mr. Southern and Mr. W. Creighton made several experiments of this kind under different barometric pressures, and at different temperatures, the mean results of which gave 954° .

In other experiments, made under the same pressures and temperatures, the quantities of heat were found 942° and 950° ; mean 949° .

(128.) Another way of arriving at an estimate of this latent heat is by means of Papin's digester, in which water may be heated to 400° without boiling. Now if, when heated to this degree, the mouth of the vessel be suddenly opened, it is found that one-fifth of the water rushes out in steam, and the remaining four-fifths is of course reduced to 212° , consequently 188° have been carried off. Dividing the whole quantity of water into five parts, the one-fifth part, carried off in the form of steam, has absorbed not only its own 188° , but also the same quantity from each of the other four parts, the whole being reduced to 212° ; it has, therefore, absorbed $188^{\circ} \times 5 = 940^{\circ}$. This estimate, however, is rather rough, as it depends so much upon the actual portion of water remaining in the vessel.

(129.) The experiments of Count Rumford give a higher result; and as his skill in such inquiries was well known, great credit has been given to his results. In these experiments the heat was measured by means of the temperature communicated to a copper vessel filled with water, which he called his calorimeter. Within this was placed a thin serpentine pipe of copper, containing the steam to be condensed; hence the fluids did not mix together, and loss by the escape of vapour was prevented.

The water which the calorimeter contained was at a lower temperature than that of the room by 5° or 6° ; and when the thermometer of the calorimeter indicated an augmentation of temperature of 10° or 12° , an end was put to the experiment. The water produced by the condensation of the vapour in the pipe was carefully weighed, and from its quantity, as well as from the heat communicated to the calorimeter, the heat developed by the vapour in its condensation was determined. As a small part of the heat communicated to the calorimeter was produced from the cooling of the water condensed in the pipe after the vapour had been changed into water, an account was kept of this heat. It was supposed that the water at the moment of condensation was at the temperature of 212° , being that of boiling water, and it was determined by calculation, what part of the heat communicated to the calorimeter must have been due to the boiling water.

The following are the details and results of two of his experiments made January 21, 1812. The duration of each was from ten to eleven minutes. The water had been boiled for some time to drive out the air which it contained before the steam was directed into the serpentine pipe of the calorimeter.

Machinery.
Watt's,
Southern's,
and Creigh-
ton's expe-
riments.

Rumford's
experi-
ments.

Manufactures.

Temperature of the Room.	State of the Calorimeter equal in specific heat to 42,909 grains of Water.			Quantity of Vapour condensed into Water.	Heat of conversion of the Water into Vapour in degrees.
	Temperature at the beginning.	Temperature at the end.	Elevation of its Temperature.		
61°	55½	67½	12¼	Grains. 457	1029.3°
62½	57	67½	10½	377	1052.3
				Mean.	1040.8

This result is considerably higher than those above stated, and higher than those more recently obtained by Dr. Ure, although his also are greater than the former.

Ure's experiments.

(130). Dr. Ure's experiments were undertaken in 1817, and were communicated to the Royal Society, and published in the *Philosophical Transactions* for 1818.

His apparatus consisted of a glass retort of very small dimensions, with a short neck inserted into a globular receiver of very thin glass, about three inches in dia-

meter. The glass was fixed steadily in the centre of Machinery 32,340 grains of water, at a known temperature, contained in a glass basin. Of the liquor whose vapour was to be examined, 200 grains were introduced into the retort, and rapidly distilled into the globe by the heat of an Argand lamp. The temperature of the air was 45°, that of the water in the basin from 42° to 43°, and the rise of temperature occasioned by the condensation of the vapour never exceeded that of the air by four degrees. As the communication of heat is very slow in bodies which differ little in temperature, the air could exercise no perceptible influence on the water in the basin during the experiment, which was always completed in five or six minutes. A thermometer of great delicacy was continually moved through the water, and its indications were read off by the aid of a lens to a small fraction of a degree.

The distillation was rapidly performed, and the author states that in the numerous repetitions of the same experiment, the accordance was every thing that could be desired. The following Table gives the mean result for water and some other fluids.

Liquid.	Specific Gravity.	Temperature of the Water in the Basin.			Boiling Point.	Heat of Conversion into Vapour.
		Beginning.	End.	Difference.		
Water	1.000	42.5°	49°	6.5°	212°	942° *
Alcohol	0.825	42	45	3	175	425.50
Sulphuric ether	0.7	42	44	2	112	302.60
Oil of turpentine	0.888	42	43.5	1.5	316	146.0
Petroleum	0.75	42.5	44	1.5	306	150.0
Nitric acid	1.494	42	45.5	3.5	165	517.0
Ammonia	0.978	42	47.5	5.5	140	840.0
Vinegar	1.007	42.5	48.5	6	...	870.0

Dr. Ure has since corrected these numbers for the loss of heat not included in his first deductions, and he makes thus the heat of conversion for water into steam 1000°, which is about a mean between all we have given, and is probably not far from the truth.

The preceding statements contain the best information we at present possess relative to the conversion of water into steam, and the quantity of heat absorbed in the conversion, which is insensible to the thermometer, and which, perhaps, may now be more advantageously stated as a general rule as follows, *i. e.* That it would require 5½ times the quantity of heat to convert a given quantity of water at 212° into steam, that would raise the temperature of the same water from 32° to 212°.

Elasticity of steam.

(131.) *On the elastic force of steam in contact with water.*—It has been seen, and the fact is generally known, that the elastic force of steam at 212° is equal to the pressure of the atmosphere, or to about 14½ pounds on a square inch; it remains for us now to report those experiments which have been undertaken to determine its elasticity at other degrees of temperature above and below 212°. Its elastic power below 212° has little to do with the application of steam as a motive power, but it is involved in the condensation, and therefore, as a part of the general inquiry, we shall give some of those

results which have been obtained at low temperatures as well as others at very high temperatures, although, perhaps, neither extreme will ever find a practical application; but theoretically they are both extremely valuable, in verifying formulæ intended to express the law of relation between different degrees of heat and the corresponding elastic force of steam.

It is not, perhaps, within our province, and is certainly not consistent with our limits, to enter into a minute description of the various methods followed by different experimenters to determine the elastic power of steam at different temperatures; at the same time, the several results thus obtained, which may be tabulated within narrow limits, will be both interesting and useful; it is proposed, therefore, in the following Table to exhibit the results which have been obtained by many very able Philosophers, and to describe one or two methods of conducting the experiments which have been thought most perfect; and lastly, to compare these several results with the different formulæ which have been given with a view of expressing the relation between the temperature and the elastic force of steam.

Tabulated elasticities of steam by different authors.

* The numbers in this column are given as corrected by Mr. Tredgold, they being erroneously given in the article referred to.

Manufac- TABLE showing the Elastic Power of Steam at different Degrees of Temperature, as resulting from the Machinery. Experiments of different Authors, within the Limits of six Atmospheres. The Degrees are those of Fahrenheit's Thermometer.

WATT.		ROBISON.		DALTON.		URE.		SOUTHERN.		TAYLOR.	
Tempera- ture.	Elasticity in inches of Mercury.	Tempera- ture.	Elasticity in inches of Mercury.	Tempera- ture.	Elasticity in inches of Mercury.	Tempera- ture.	Elasticity in inches of Mercury.	Tempera- ture.	Elasticity in inches of Mercury.	Tempera- ture.	Elasticity in inches of Mercury.
First Series.											
55°	0.15	32°	0.0	32°	0.2	24°	0.170	32°	0.16	212°	30.00
74	0.65	40	0.1	43½	0.297	32	0.200	42	0.23	220	34.95
81	0.80	50	0.2	54½	0.435	40	0.250	52	0.35	230	41.51
95	1.30	60	0.35	65½	0.63	50	0.360	62	0.52	240	50.00
104	1.75	70	0.55	77	0.91	55	0.416	72	0.73	250	59.12
118	2.68	80	0.82	88½	1.29	60	0.516	82	1.02	260	70.10
128	3.60	90	1.18	99½	1.82	70	0.726	92	1.42	270	82.50
135	4.53	100	1.6	110½	2.54	80	1.010	102	1.96	280	97.75
142	5.46	110	2.25	122	3.5	90	1.360	112	2.66	290	114.50
148	6.40	120	3.0	133½	4.76	100	1.860	122	3.58	300	133.75
153	7.325	130	3.95	144½	6.45	110	2.456	132	4.71	320	179.40
157	8.25	140	5.15	155½	8.55	120	3.300	142	6.10		
161	9.18	150	6.72	167	11.25	130	4.366	152	7.90		
164	10.10	160	8.65	178½	14.6	140	5.770	162	10.05		
167	11.07	170	11.05	189½	18.8	150	7.53	172	12.72		
172	11.95	180	14.05	200½	24.0	160	9.600	182	16.01		
175	12.88	190	17.85	212	30.0	170	12.050	212	30.00		
177.5	13.81	200	22.62	Dalton Second Series.		180	15.160	250.3	60.00		
180	14.73	210	28.68	36	0.29	190	19.000	293.4	120.00		
182.5	15.66	220	35.8	64	0.75	200	23.600	343.6	240.00		
185	16.58	230	44.5	96	1.95	210	28.880				
187	17.51	240	54.9	132	5.07	212	30.000				
189	18.45	250	66.8	173	13.18	220	35.540				
191	19.38	260	80.3	220	34.20	225	39.110				
193.5	20.34	270	94.1	272	88.9	230	43.100				
196.5	21.26	280	105.9	340	231.0	240	51.700				
						250	61.900				
						260	72.300				
						270	86.300				
						280	101.900				
						290	120.150				
						295	129.000				
						300	139.700				
						310	161.300				
						312	167.000				
						312	165.5				

The above are the principal results that have been obtained relative to the elastic power of steam within the limits of six atmospheres. Since these, however, experiments have been carried to the extent of twenty-four atmospheres, which will be given below; but it will be proper first to describe the method adopted by Dr. Robison and Dr. Ure, in obtaining the results stated in the preceding Table; these being not only free from several objections which have been made against other methods, but the latter in particular is also very simple, and applicable to similar inquiries for other liquids.

(132.) Dr. Robison's apparatus consisted of a small digester of copper A B C D, (pl. ix. fig. 1,) the top of which had a thermometer inserted through the centre, and a loaded valve at V, with a third hole for inserting a barometer tube S G F to ascertain the force at lower temperatures than 212°. The force of the higher temperatures was measured by the steelyard on the valve, and a plug was inserted in the place of the tube S G F; but the results with the valve were irregular and not satisfactory. Hence the glass tube M N K (fig. 1, a) having a cistern, L, for mercury, was adapted to the hole in the digester, and instead of measuring the force by the valve, it was measured by the ascent of the mercury in the tube M N. The digester was heated by a lamp.

To determine the pressure at temperatures below 212°

the tube S G F was inserted as in the figure, and a basin of mercury provided at F. The lamp being applied, the water in the digester produced steam till it issued at both the pipe and the valve F, so as to expel the air; the lamp being removed, and both the valve and tube being closed, the latter by immersing it in the mercury, the mercury rose in the tube F G, as the apparatus cooled, and the heights corresponding to different temperatures were noted; like observations were made as it was reheated. To determine the pressure at higher temperatures with the apparatus, the end K of the tube M N K was inserted at E, and as the temperature increased, the pressure of the steam in the cistern L caused the mercury to ascend, and consequently afforded the means of measuring the force of the steam.

The objection to this mode of trial is that the temperature of the mercury must be continually changing during the trial, and steam must either be condensing or generating on its surface during the time of observation. At each observation the temperature of the whole of the apparatus ought to be the same, and then the column exhibiting the pressure ought to be reduced to its equivalent at the mean temperature. The only observation in which these circumstances could have place was that which appears to have been made when the thermometer was at 42°, then the column in the syphon was 27.7 and the barometer stood at 29.84; the difference in the

Manufac-
tures.

Dr. Ure's
apparatus
described.
Pl. ix.
Fig. 2, 3, 4.

force of steam at 42° , and is 0.14 inches. By cooling down to 32° the force was not perceptibly different, and we know from later trials that this is nearly correct.

(133.) In plate ix. fig. 2 represents the construction employed by Dr. Ure for temperatures under and a little above the boiling point, fig. 3 and 4 were used for high temperatures; the last is the more convenient of the two. It was suspended from a lofty window ceiling, and placed with the tube L D in a truly vertical position by means of a plumb line. One simple principle pervades the whole train of experiments, which is, that the progressive increase of elastic force is developed by heat from the liquid incumbent on the mercury at *l*, measured by the length of column which must be added over L, in order to restore the quicksilver to its primitive level at *l*. These two stations, or points of departure, are nicely defined by a ring of fine platina wire twisted round the tube.

At the commencement of the experiments, after the liquid, well freed from air, has been let up, the quicksilver is made to coincide with the edge of the ring L, by cautiously pouring mercury in a slender stream into the open leg of the syphon D. The level ring at L is then carefully adjusted.

From the mode of conducting the experiments there remained always a quantity of liquid in contact with the vapour, a circumstance essential to accuracy in this research. Suppose the temperature of the water or the oil in A (fig. 2) to be 32° , as denoted by a delicate thermometer, or by the liquefaction of ice, and let L D be a column equal to the atmospheric pressure; communicate heat to the cylinder A, by means of two Argand flames playing gently against its shoulder at each side.

When the thermometer indicates 42° modify the flames, or remove them so as to maintain an uniform temperature for a few minutes. Then the elasticity will be faithfully represented and measured by the mercurial column which we must add over D, in order to return the quicksilver to the line *l*, its zero or initial level.

A piece of cork, E, is fixed between the parallel legs of the syphon to sustain it, and to serve as a point by which the whole is steadily suspended.

For temperatures above the boiling point, the part of the syphon under E is evidently superfluous, merely containing in its two legs a useless weight of equipoised mercury. Accordingly for high heats, either apparatus (fig. 3 or 4) is employed, and the same method of procedure is adopted. The aperture at O (fig. 3) admits the bulb of the thermometer, which rests against the tube. The recurved part of the tube is filled with mercury, and then a little liquid is passed through it to the sealed end. Heat is applied by an Argand flame to the bottom of C, which is filled with oil or water, and the temperature is kept steadily at 212° for some minutes. Then a few drops of quicksilver may require to be added at D, till L and *l* be in the same horizontal plane. The further conduct of the experiment differs in no respect from what has been described. The liquid in C is progressively heated, and at each stage mercury is progressively added over L to restore the initial level or volume at *l*, by equipoising the progressive elasticity; the column above L being the accession of elastic force: when it is wished to extend this column very high, the vertical tube requires to be placed for support in the groove of a long wooden prism.

We cannot enter into a description of the other methods which have been had recourse to in the pursuit of

this inquiry; but to such of our readers as are desirous of examining the different processes, the following references may be useful. Watt's experiments are detailed in Robison's *Mech. Phil.* by Brewster, vol. ii. p. 33, 34. Dr. Robison's own experiments, as above stated, are given in the same volume, p. 36. Dalton's, in the *Manchester Memoirs*. See also *Phil. Journal*, by Nicholson, vol. vi.; *Annals of Philosophy*, vol. x.; Southern's; Robison's *Mech. Phil.* vol. ii. p. 173; Taylor's *Phil. Mag.* vol. ix.

(134.) In no one of the preceding experiments the pressure exceeded six atmospheres, but the great importance which was attached to obtaining a perfect knowledge of the elastic power of steam at higher temperatures, induced the French Government to request the members of the Institute of France to undertake a new series of experiments on this subject. These were placed under the able direction of MM. Baron de Prony, Arago, Girard, and Du Long, who in 1830 made their Report to the Institute, by whom it was addressed and presented to the Minister of the Interior.

These results are too important to be passed over in silence, although it will be impossible for us to explain the many details which necessarily attend such a course of experiments, in order to ensure that degree of precision which it was so desirable they should possess. The reader, however, without this, will not doubt of their accuracy, from the known character of the distinguished Philosophers by whom the experiments were conducted, and the means which were put into their hands by the French Government. Those who are desirous of examining the whole in detail, are referred to the *Exposé des Recherches faites par Ordre de l'Académie Royale des Sciences pour déterminer les Forces Elastiques de la Vapeur d'Eau à de hautes Températures*, published by Firmin Didot, Frères, Paris, 1830.

The experiments may be divided into two parts: first, those by which the compression of the same volume of air was ascertained for different pressures of mercury, varying from one atmosphere to 27 atmospheres, that is from 30 inches of mercury to nearly 70 feet; and secondly, those which, by employing the compressions thus ascertained, were made to determine the elastic power of steam, till that power amounted to the pressure of 24 atmospheres.

(135.) The apparatus by which the first course of experiments were conducted is shown in plate ix. fig. 5, where *s* represents a metallic vessel with two tubes projecting from its bottom, and containing about 100 pounds of mercury. This vessel was furnished at top with a forcing pump L. To the end of the tube *a* was fixed a barometer tube *aa* containing air, and this again was covered by a larger glass vessel, filled with water from the cistern *e*, which water was discharged at *r*, as fast as it was supplied at *a*, whereby the temperature of the air in the tube *aa* was preserved of the uniform temperature of the water in the cistern *e*. To the other extremity of the tube was fixed a length of barometer tube of two metres, and thirteen such tubes being accurately united by the means described in the *Exposé*, were placed end to end to the height of more than $85\frac{1}{2}$ feet English measure. The diameter of the tubes was 5 millimetres, or about two-tenths of an English inch, and of the same thickness, the tube *aa* having also the same diameter and thickness, and its length 1.7 metres, or 67 English inches. The weights and pulleys shown at P P were employed to relieve the lower tubes from the weight of

Machinery

Elastic power of steam at high temperatures.

Experiments made by order of the French Government by Members of the Institute.

Manufactures.

those above them, and were of course repeated at every stage or point of union of the tubes. The scale *g* was for ascertaining the elevation of the mercury, as the scale shown on the other branch was for measuring the same in the tube *a a*, or the compression of the air; the apparatus shown at *q, r, u* was rendered necessary for adjusting the vernier, in consequence of the interposed water in the outer tube *m m'*, the temperature of which was shown by the thermometer *X*. Every necessary precaution being now taken to observe the level of the surfaces of the mercury in the two branches, air was forced into the vessel by the pump, which caused the mercury to rise in both the open long tube *d d*, and in the close tube *a a*, and thus the compression and elasticity of the same volume of enclosed air was ascertained, as given in the following Table, for three distinct series of experiments, and for different pressures varying from one to twenty-seven atmospheres.

TABLE showing the Elastic Force of the same Volume of Atmospheric Air under different Pressures, Temperature nearly constant.

Elasticities expressed in Atmospheres of 0.76 metres.	Elasticities in centimetres of Mercury.	Observed Volume.	Calculated Volume.	Temperature in Centigrade degrees.
First Series.				
1	80.09	479.73	....	14.3
2	156.9	244.687	244.88	14.3
4	326.706	117.168	117.6	14.4
4.8	365.452	104.578	105.208	14.5
6.5	504.072	75.976	76.222	Ditto.
7	557.176	68.910	69.007	Ditto.
9	688.54	55.45	55.801	Ditto.
11.6	883.94	43.359	43.466	Ditto.
12	933.346	40.974	41.137	Ditto.
14	1070.862	35.767	35.881	Ditto.
Second Series.				
1	79.497	481.806	....	13.3
2	156.112	244.986	245.205	13.5
4	313.686	121.542	121.989	13.6
4.7	362.11	104.795	105.488	12.5
5	381.096	99.59	100.253	Ditto.
6.1	464.752	81.787	82.218	12.6
6.6	508.07	74.773	75.208	Ditto.
6.6	506.592	74.985	75.427	Ditto.
7.6	578.162	65.723	66.09	Ditto.
7.6	580.002	65.473	65.881	Ditto.
8	637.108	59.767	60.039	13.8
11.5	875.052	43.428	43.682	13.7
11.6	881.202	43.146	43.378	Ditto.
12	962.108	39.679	39.758	14.5
16.6	1269.132	30.136	30.140	13.7
Third Series.				
1	76	501.3	....	13
4.75	361.248	105.247	105.47	Ditto.
4.94	375.718	101.216	101.412	Ditto.
5	381.228	99.692	99.946	Ditto.
6	462.518	82.286	82.380	Ditto.
6.58	500.078	76.095	76.193	Ditto.
7.6	573.738	66.216	66.417	Ditto.
11.3	859.624	44.308	44.325	Ditto.
13	999.236	37.851	38.132	Ditto.
16.5	1262.000	30.119	30.192	Ditto.
17	1324.506	28.664	28.770	Ditto.
19	1466.736	25.885	25.978	Ditto.
21.7	1653.49	22.968	23.044	Ditto.
21.7	1658.44	22.879	22.972	Ditto.
24	1843.85	20.547	20.665	Ditto.
26.5	2023.666	18.833	18.872	Ditto.
27	2049.868	18.525	18.588	Ditto.

The preceding results are no otherwise connected with our present inquiry than as they served in the subsequent experiments to furnish a measure of the degrees of pressure due to the different degrees of temperature of the steam. At the same time, they are interesting in proving that the law first pointed out by Mariotte, (that the space into which air and other elastic fluids are compressed is inversely as the pressure,) is true as far as these experiments extend, viz. to twenty-seven atmospheres; whereas it had been supposed to have begun to fail under much less pressures.

(136.) In the second division of the experiments the long tube was removed, and the passage stopped, while the forcing pump was replaced by a steam pipe from a powerful steam boiler; the same air was preserved in the close tube, and the pressure of the steam was now ascertained by the compression of the air according to the scale obtained in the preceding experiments. The experiments were carried as far as to a pressure of twenty-four atmospheres, or to 18 metres of mercury, as in the following Table. The two columns marked great and small thermometer indicate the reading of a long and short thermometer immersed, the one some depth in the water of the boiler, and the other in the steam above the water. The last column but one indicates the state of the thermometer at the time of observation; the letters *a*, or *a, l*, expressing that the mercury was ascending, or ascending slowly; *p* that it was ascending quickly; *max.* the maximum.

TABLE of the Elastic Force of Steam at various Temperatures, from 123° to 224°. By MM. Prony, Arago, Girard, and Du Long.

No. of Experiments.	Small Thermometer Centigrade.	Large Thermometer Centigrade.	Elastic force in metres of Mercury.	Elastic force in Atmospheres of 0.76 metres.	Condition of the Observation.	Elastic force reduced to metres of Mercury at 0°.
1	122.97	123.7	1.62916	2.14	max.	1.62916
2	132.58	132.82	2.1823	2.87	a.	2.1767
3	132.64	133.3	2.18726	2.88	p. max.	2.1816
4	137.70	138.3	2.54456	2.348	a.	2.5386
5	149.54	149.7	3.484	4.584	max.	3.4759
6	157.87	151.9	3.69536	4.86	a.	3.6868
7	153.64	153.7	3.8905	5.12	a.	3.881
8	163.00	163.4	4.9489	6.51	max.	4.9383
9	168.40	168.5	5.61754	7.391	max.	5.6054
10	169.57	169.4	5.78624	7.613	a. l.	5.7737
11	171.88	172.34	6.167	8.114	a.	6.151
12	180.71	180.7	7.51874	9.893	p. max.	7.5001
13	183.70	183.7	8.0562	10.6	a.	8.0352
14	186.80	187.1	8.72218	11.48	a. l.	8.6995
15	188.30	188.5	8.8631	11.66	max.	8.840
16	193.70	193.7	10.0254	13.19	a.	9.9989
17	198.55	198.5	11.047	14.53	a. l.	11.019
18	202.00	201.75	11.8929	15.67	a.	11.862
19	203.40	204.17	12.321	16.21	a. l.	12.2903
20	206.17	206.10	13.0211	17.13	a.	12.9872
21	206.40	206.8	13.0955	17.23	max.	13.061
22	207.00	207.4	13.167	17.3	p. max.	13.1276
23	208.45	208.9	13.7204	18.05	a.	13.6843
24	209.10	209.13	13.8049	18.16	a.	13.769
25	201.47	210.5	14.1001	18.55	p. max.	14.0634
26	215.07	215.3	15.5407	20.44	a.	15.4995
27	217.23	217.5	16.1948	21.31	a.	16.1528
28	218.3	218.4	16.226	21.6	p. max.	16.3816
29	220.4	220.8	17.2248	22.66	a.	17.1826
30	223.88	224.15	18.2343	23.994	max.	18.1894

(137.) Deduction of formulæ expressing the relation between temperature and elasticity.

On casting one's eye over the preceding Tables we

Machinery.

Manufactures. shall find a tolerable accordance in the results of the different experiments, but such an extremely apparent irregularity between the temperatures and elasticities, as almost to discourage one from attempting to obtain a formula that shall express the relations between them. Numerous attempts, however, of this kind have been made by different Mathematicians and Philosophers, some of which it will be well to examine and compare in this place.

By Dalton. Dalton inferred from the experiments which he made, that the relation between the temperature and elasticity was such, that while the former increased in an arithmetical progression, the latter increased in a geometrical progression, or very nearly.

By Ure. Prony, Laplace, Biot, and Ivory, have each given formulæ for expressing this relation, but they have been found generally defective in the higher pressures. Dr. Ure proposed not a formula but a sort of principle of interpolation, which agrees pretty well with minor pressures, viz. beginning at the temperature 212° of Fahrenheit, at which the pressure or elastic force is 30 inches. To find it for 222°, he directs to multiply 30 by 1.23, for 232°, multiply the elastic force of 222° by 1.22, &c. always for the next 10° higher, multiplying the preceding pressure by the last multiplier reduced by 1, in the hundreds place of decimals. Below 212°, the pressure is obtained in a similar way for every tenth degree, the first by dividing by 1.24, then for the next 10° by 1.25, 1.26, &c.

This, however, must necessarily fail after the addition of 230°, because after this the elastic forces would by this rule decrease, which is not likely to be the case.

By M. Roche. M. Roche, Professor of Mathematics at Toulon, proposed the following formula :

$$f = 760 \times 10^{\frac{m t}{11 + 0.03 t}};$$

where f is the elastic force of the steam in millimetres of mercury, t the temperature in degrees of the Centigrade thermometer, reckoned from 100°, positive above and negative below, and m a mean coefficient to be determined by experiment. This value, from a comparison of the preceding experiments, is $m = 0.1645$, which, being substituted for m , and the equation expressed in terms of t , it becomes

$$t = \frac{11 (\log. f - \log. 760)}{0.1644 - 0.03 (\log. f - \log. 760)}.$$

This is nearly the only formula of the exponential kind which approximates towards the truth for high temperatures; it would be useless, therefore, to give them. Most others are of the general forms

$$f = \left(\frac{t \pm a}{q} \right)^n \text{ or } t \pm a = q^n \sqrt[n]{f};$$

where t denotes the temperature, $\frac{1}{n}$, an index to some root

of f , the elastic force, and q and a numbers to be determined by experiment. That is, they all suppose the temperature to commence from some certain point, where the elasticity of the vapour is zero, and then assume that, for any number of degrees above this point, the elasticity is proportional to some power of these.

Thus Mr. Tredgold obtains

$$f = \left(\frac{t + 75^\circ}{85} \right)^6 \text{ or } t = 85 \sqrt[6]{f - 75^\circ};$$

in which t is the temperature on the Centigrade thermometer, and f centimetres of mercury. M. Coriolis obtains

$$f = \left(\frac{0.01878 t + 1}{2.878} \right)^{5.335} \text{ or } t = \frac{2.878 \sqrt[5.335]{f - 1}}{0.01878};$$

where t are Centigrade degrees as above, but f is expressed in atmospheres of 0.76 metres of mercury.

MM. Prony, Arago, &c., in the *Exposé* above referred to, have

$$f = (0.7153 t + 1)^5 \text{ or } t = \frac{\sqrt[5]{f - 1}}{0.7153};$$

where t are the degrees above 100°, and 1 is taken to represent an interval of 100°.

The following Table exhibits a comparison of these four formulæ for different pressures, varying from two to twenty-four atmospheres.

TABLE exhibiting the Approximations of the Elastic Force of Steam, and the corresponding Temperatures, by four different Formulæ.

No of Observations.	Elasticities in metres of Mercury at 0°.	Elasticities in Atmospheres of 0.76 metres.	Observed Temperatures, Centigrade.	Temperatures by Tredgold's formula.	Temperatures by the formula of De Roche.	Temperatures by the formula of Coriolis.	Temperatures by formula of the <i>Exposé</i> .
1	1.62916	2.14	123.7	123.54	123.58	123.45	122.97
3	2.1816	2.8705	133.3	133.54	133.43	133.34	132.9
5	3.4759	4.5735	149.7	150.39	150.23	150.3	149.77
8	4.9383	6.4977	163.4	164.06	163.9	164.0	163.47
9	5.6054	7.3755	168.5	169.07	169.09	169.3	168.7
15	8.840	11.632	188.5	188.44	188.63	189.02	188.6
21	13.061	17.185	206.8	206.15	207.04	207.43	207.2
22	13.137	17.285	207.4	206.3	206.94	207.68	207.5
25	14.0634	18.504	210.5	209.55	210.3	211.06	210.8
28	16.3816	21.555	218.4	216.29	218.01	218.66	218.5
30	18.1894	23.934	224.15	222.19	233.4	224.0	224.02

The agreement in all these four cases is very remarkable, considering that they were all, except the last, found from experiments which did not exceed six atmospheres. It is indeed obvious from these, that the elastic power of steam increases very nearly as the fifth or sixth power of the temperature, the latter commencing from some point below the zero; but this exact point and the exact power remains still to be determined.

We shall conclude this part, on the elasticity of steam in contact with water, with the following Table; in which from 1 to 4 atmospheres are computed by Tredgold's formula, and from 4 to 50 by the formula given in the *Exposé*. As far as 8 atmospheres, the computation is made for every half atmosphere, from 8 to 24 for every atmosphere, and from 25 to 50 for every 5 atmospheres. It is proper to observe that Mr. Tredgold's formula agrees very well for pressures that are less than one atmosphere, which is not the case with the formula given by MM. Prony and Arago.

Manufactures.

TABLE of the Elastic Force of Steam in contact with Water from 1 to 50 Atmospheres.

Elasticity in Atmosphere.	Elasticity in Metres of Mercury at 0°	Temperatures in degrees of the Centigrade.	Pressure on a square Centimetre in Kilogrammes.	Pressures on a square inch English.
1	0.7600	100°	1.033	14.75lbs
1½	1.1400	112.2	1.549	21.82
2	1.5200	121.4	2.066	29.50
2½	1.9000	128.8	2.582	36.57
3	2.280	135.1	3.099	44.25
3½	2.66	140.6	3.615	51.32
4	3.04	145.4 (1)	4.132	59.00
4½	3.42	149.06	4.648	66.07
5	3.80	153.08	5.165	73.75
5½	4.18	156.8	5.681	80.82
6	4.56	160.2	6.198	88.50
6½	4.94	163.48	6.714	95.57
7	5.32	166.5	7.231	103.25
7½	5.70	169.37	7.747	110.32
8	6.08	172.1	8.264	118.00
9	6.84	177.1	9.297	132.75
10	7.60	181.6	10.33	147.50
11	8.36	186.03	11.363	162.25
12	9.12	190.0	12.396	177.00
13	9.88	193.7	13.429	191.75
14	10.64	197.19	14.462	206.50
15	11.40	200.48	15.495	221.25
16	12.16	203.60	16.528	236.00
17	12.92	206.57	17.561	250.75
18	13.68	209.4	18.594	265.50
19	14.44	212.1	19.627	280.25
20	15.20	214.7	20.660	295.00
21	15.96	217.2	21.693	319.75
22	16.72	219.6	22.726	334.50
23	17.48	221.9	23.759	349.25
24	18.24	224.2	24.792	354.00
25	19.00	226.3	25.824	368.75
30	22.80	236.2	30.990	442.50
35	26.60	244.85	36.155	516.25
40	30.40	252.55	41.320	590.00
45	34.20	259.52	46.485	663.75
50	38.00	265.89	57.650	737.50

(138.) Of the Specific Gravity of Steam in contact with Water at different Degrees of Temperature.

Density of steam at different temperatures.

The amount of latent heat, or the quantity of heat absorbed in the conversion of water at 212° into steam, and the elasticity of steam at various temperatures, have been treated of in the preceding pages; we have now to show the density of steam at various temperatures and pressures, which is very necessary to be known for various objects, and particularly in the process of condensation; in order properly to proportion the capacity of the condenser for different quantities of steam. It appears from the experiments of Mr. Dalton, that the weight of a cubic foot of steam at 212° is 253 grains; others give it as 254.7 grains. Now a cubic foot of water weighs 62½ pounds, each pound containing 7000 grains,

therefore $\frac{62\frac{1}{2} \times 7000}{254.7} = 1711$, the number of volumes

which a given volume of water occupies in the form of steam at 212°.

Now assuming the density of steam in contact with its water of generation to be proportional to its elastic force, we have, as thirty inches of mercury, the pressure at 212°, is to the elasticity at any other temperature, so is 254.7 the grains of aqueous vapours in the former case to that in the latter. In this way the following Table has been computed.

TABLE showing the Pressure, Specific Gravity of Steam, and Weight of a Cubic Foot at different Temperatures.

Pressure in inches of Mercury.	Temperature Fahrenheit therm.	Weight of Cubic foot in grains.	Specific gravity, air being unity.	Pressure in inches of Mercury.	Temperature Fahrenheit therm.	Weight of Cubic foot in grains.	Specific gravity, air being unity.
0.55	60°00	6.10	0.0115	75.00	263.00	593.50	1.123
1.00	77.00	10.70	0.0202	90.00	274.70	700.00	1.33
2.00	98.70	20.50	0.0388	105.00	284.50	810.00	1.53
3.00	112.50	30.00	0.0568	120.00	293.10	910.00	1.728
4.00	123.00	39.00	0.0744	150.00	308.00	1110.00	2.12
7.50	147.60	71.00	0.134	180.00	320.60	1317.00	2.5
15.00	178.00	135.00	0.255	210.00	331.50	1520.00	2.88
22.50	197.40	196.00	0.371	240.00	341.20	1660.00	3.25
30.00	212.00	254.70	0.484	270.00	350.00	1910.00	3.61
35.00	220.00	292.00	0.553	300.00	358.00	2100.00	3.97
45.00	233.80	363.00	0.687	600.00	414.00	3940.00	7.44
52.50	242.50	427.00	0.81	900.00	450.00	5670.00	10.75
60.00	250.20	483.00	0.915	1200.00	477.00	7350.00	13.88

(139.) Of the Elastic Force of Steam when not in contact with its Water of Generation.

In all that has preceded, the steam has been supposed in contact with its water of generation, and of the same temperature with it, in which case both the increased density of the steam, and its increased elasticity from heat, contribute to increase its elastic force; but when steam is cut off from its generating water, an increase of temperature does not increase its density, but merely its elastic force, the density remaining constant; and, therefore, the laws of its increasing force are altogether different from the former, and much more simple and easier to express and comprehend.

It has been well ascertained that an elastic vapour, steam for example, in having its temperature raised from the temperature 0° on Fahrenheit's scale, is expanded $\frac{1}{459}$ th part for every degree on that scale.

Let v denote the volume a given quantity of steam occupies at 0°, then the volume at t degrees will be

$$v' = v + \frac{t v}{459},$$

and at t' degrees $v'' = v + \frac{t' v}{459}$

By the first equation we obtain

$$v = \frac{459 v'}{459 + t}.$$

Substituting this value of v in the second equation,

$$v'' = v \times \frac{459 + t'}{459 + t}.$$

Whence the volume of steam v , being given for any temperature t , the volume v'' it would occupy, the pressure remaining the same, may be found by the above formula; or in words,—

To the temperature before and after expansion add 459; divide the greater number by the less, and multiply the quotient by the volume before expansion, and the product will be the volume due to the higher temperature.

Or divide the lesser number by the greater, and multiply the quotient by the volume at the higher temperature, and the product will give the volume at the lower.

We here suppose the pressure to remain the same; but if the volume remain the same, then the elastic force

Manufactures. will be increased in the same proportions as the volumes would be under a constant pressure.

If, therefore, f denotes the elastic force at the temperature t ,

$$f' = f \times \frac{459 + t'}{459 + t}$$

will be the elastic force at the temperature t' , the space remaining constant.

By means of these formulæ we may readily find the volume a given measure of water would occupy in steam of any given elasticity and temperature. It has been seen, for example, that a cubic foot of steam at 212° contains 254.7 grains of vapour, and that it occupies 1711 times the space these grains in the form of water would occupy at 60° , and that the pressure of the steam at 212° is 30 inches of mercury.

Now the space a cubic foot of steam would occupy at the temperature t' is by the formula,

$$v = 1711 \times \frac{459 + t'}{459 + 212} = 2.55 (459 + t');$$

whence again by the second formula, f being in this case 30 inches, we have

$$f' = 30 \times 2.55 (459 + t') = 76.5 (459 + t').$$

That is, to the given temperature add 459, and multiply the sum by 76.5, which will give the elastic force, the volume remaining the same. This being again divided by the inches of mercury due to the pressure, will give the number of volumes a given volume of water would occupy at the proposed temperature and pressure.

By these means the following Table has been computed, showing the number of cubic feet one cubic foot of water would occupy at the different pressures and temperature stated therein.

TABLE showing the Number of Cubic Feet of Steam which may be formed by one Cubic Foot of Water, at different Temperatures and Pressures.

Pressures in inches of Mercury.	Temperature, Fahrenheit.	Cubic feet.	Pressures in inches of Mercury.	Temperature, Fahrenheit.	Cubic feet.
0.55	60°	72190	75	263.5	737
1.00	77	41010	90	274.7	623
2.00	98.7	21400	105	284.5	542
3.00	112.5	14570	120	293.1	479
4.00	123	11130	150	308	391
7.50	147.6	6187	180	320.6	331
15.00	178	3249	210	331.5	288
22.50	197.4	2232	240	341.2	255
30.00	212	1711	270	350	229
35.00	220	1497	300	358	209
45.00	233.8	1178	600	414	111
52.50	242.5	1022	900	450	77
60.00	250.2	905	1200	477	60

(140.) *On the Velocity with which Steam rushes into a Vacuum or into a Fluid of greater Rarity than itself.*

The method of computation in this case is precisely the same as has been explained in the article PNEUMATICS; that is, we must, after knowing the temperature of the steam and its pressure, compute the height of a uniform atmosphere which would produce the same pressure; then the velocity which a heavy body would acquire in falling through this height is the velocity with which the steam would rush into vacuo. And if the question

be the velocity with which it would rush into another fluid of greater rarity than itself, then find the height of a uniform atmosphere equal to the difference of pressure, and the velocity a heavy body would acquire in falling through this height will be the velocity sought. This, however, supposes that the steam experiences no resistance in its motion, but that the aperture is open and the passage made in a right line; and in this case it being the height of the atmosphere, we shall have the velocity

$$v = 8 \sqrt{h}.$$

But it is said that in consequence of the bendings and other hinderances which the steam encounters in passing along pipes, that the multiple 8 must be reduced to $6\frac{1}{2}$, 6, or 5, according to circumstances; and as it is difficult to form a correct judgment as to the amount of this reduction, it is obvious that but little practical good can be derived from such investigations. It will be seen, however, that, even with the smaller multipliers, the velocity is so great that the relative speed of the piston is very inconsiderable, and may be rejected in estimating the effect of the steam upon it, as we have already remarked. (Art. 25.)

This velocity, if we had the means of making a proper estimate of the retardations, that is, if we could arrive at its actual practical amount, might be advantageously employed to ascertain the proper dimensions of steam pipes, passages, and valves; but we apprehend that these can never be computed theoretically. Experience here is our only guide, and this seems to point out that in low-pressure engines the passages ought to be in diameter about $\frac{1}{3}$ th the diameter of the piston, and consequently the area about $\frac{1}{9}$ th; others reckon about an inch per horse for the area of the passages, which does not differ greatly from the above dimensions.

(141.) *Of the Quantity of Fuel requisite to produce a given Quantity of Steam; and on its Efficiency as a Mechanical Agent.*

In the preceding sections have been stated all the more important properties of steam; it will be proper in this place to offer a few remarks and experimental results relative to the power of different kinds of fuel. The effect produced from a certain weight of fuel depends of course upon the perfection of the combustion; it is necessary, therefore, before any comparison can be formed, to be assured that the different experiments have all been conducted on the best principles of producing combustion; this may throw some doubts on the following results, at the same time the celebrity of the authors must assure us that they are not very erroneous.

The trials of the quantity of steam a given quantity of fuel will produce, are by no means so numerous as might be expected by those who are unacquainted with the difficulty of ascertaining the results with precision. A practical man shrinks from the task of making accurate trials, either in consequence of the great degree of attention and labour they require, or of the expense attending the process; merely theoretical men have not the means; and it would appear that those who may be supposed to have both time and means at command, too often want the disposition.

The following are amongst the best results we can quote relative to this inquiry.

Quantity and efficiency of fuel.

Manufactures. TABLE showing the Quantity of Heat produceable from different Kinds of Fuel.

Different kinds of Fuel experimented on.	Pounds of Water heated 1° by 1 pound of Fuel.	Pounds of Water at 52° converted into Steam at 220°.	Pounds of Fuel to transform a cubic foot of Water 52° into Steam 220°.
Newcastle or Swan-sea coal, according to Mr. Watt.	6950	5.93	10.5
Newcastle, according to Dr. Black.	10400	8.9	7.0
Ditto Wall's-end coal, Tredgold.	8675	7.4	8.75
Wednesbury coal, according to Mr. Watt.	9230	7.9	7.9
Pinewood, (dry,) Count.	10050	8.6	7.25
Rumford.	5200	4.45	14.0
Oakwood, (dry,) ditto.	7800	6.68	9.34
Compact peat from Dartmore, Tredgold.	6500	5.56	11.67
Culm, Glasgow, ditto.	3618	3.1	20.02
Culm, Welsh, ditto.	5662	4.85	12.9
	2400	2.05	30.5
	3330	2.85	22.0
	4175	3.56	17.5

Efficiency of fuel in the production of steam and steam power.

Sleek or refuse small coal produces about three-fourths of the effect of good coal of the same species.

(142.) *Of the efficiency of a given quantity of fuel.*—Unfortunately there appears from the preceding Table to be great uncertainty in the result obtainable from a certain weight of fuel. Mr. Watt's results vary between the limits 6.9 and 10.4 in estimating the quantity of water raised one degree of temperature by a given weight of coal, and between the limits 10½ and 7 in estimating the weight of coals requisite to convert a cubic foot of water into steam; and we cannot, therefore, from these expect to arrive at any very definite result in the estimation of the efficiency of fuel in general. Without referring, then, to the preceding results, which may be said to be obtained from experiments comparatively on a small scale, we shall, in the following estimate, adopt the numbers of Mr. Davies Gilbert, which appear to be drawn from observations on a very large scale. There is certainly no place in the world in which the production of steam is so well understood as in the mining district of Cornwall, no place in which a given weight of coal is rendered so efficient; and, we may add, that there are few men, if there be any one, who has a better theoretical knowledge of steam and the steam-engine than the gentleman above named, whose situation as President of the Cornwall Geological Society affords him the means of acquiring the best information on these subjects. Mr. Gilbert, in a paper read before the Royal Society in 1827, enters into this question, that is, the relation which subsists between the quantity of fuel consumed and the effect produced in different engines, from the actual practical results of the different mine engines in the above district. In order to estimate the efficiency of steam acting uniformly with its entire force, at a power corresponding to 30 inches of mercury in reference to the consumption of one bushel of coals, weighing at a medium 84 pounds, he assumes from the mean of repeated experiments, which agrees, however, nearly with the minimum of Mr. Watt's experiments in the preceding Table, that seven pounds of coals will convert one cubic foot of water into steam, or that one bushel of coals will convert 14 cubic feet of water from the mean temperature into steam. His estimate of the

quantity of space a given quantity of water occupies in the form of steam, is less also than has been stated in the preceding pages of this Chapter: he considers it to occupy only 1330 times the original bulk, whereas it is computed (Art. 133.) from Dalton's experiments to occupy 1711 times. Taking, however, Mr. Gilbert's number, 14 cubic feet of water multiplied by 1330 gives 18,620 cubic feet occupied by the steam producible from one bushel of coal; this occupied with water would be $18,620 \times 62\frac{1}{2} = 1,150,410$ pounds; and as 30 inches' pressure of mercury is equal to 33.92 feet of water, it appears that, the vacuum being produced, one bushel of coal is sufficient to raise 1,150,410 pounds to a height of 33.92 feet, or 39,361,000 pounds a foot high; and if, instead of considering them to occupy only 1330 times the bulk of water, we take Mr. Dalton's number, 1711, there would result,

$$\frac{39,361,000 \times 1711}{1330} = 50,607,000 \text{ pounds}$$

one foot high for the efficiency of one bushel of coals; so that on this estimate we may state in round numbers, that one bushel of coals is competent to raising 50,000,000 pounds one foot high. The estimated horsepower, we have seen, will raise 33,000 pounds one foot high in a minute, or $33,000 \times 60 = 1,980,000$ pounds in an hour; hence a bushel of coals is equivalent to the performance of a horse for about 20 hours on the former estimate, and for more than 25 hours on the latter. Taking the least, it appears that the consumption of 4.1 pounds of coals will produce the mechanical effect of one horse for an hour. This, however, supposes every thing in the abstract, that the vacuum is produced, and the water forced up without friction or impediments of any kind; but in small engines where the friction is considerable, and other impediments are to be overcome, it is generally found that from 7 to 10 pounds of coals are required to perform the estimated duty of a horse for an hour; which estimate has been adopted in Art. 2. in comparing the effect of different first movers.

Seeing, then, that from 40,000,000 to 50,000,000 is the full efficiency of one bushel of coals, it will be considered extraordinary that, through the intervention of an engine, and the skill and ingenuity of man, this natural efficiency of steam may be, and is actually made to produce double the above effect. In illustrating this mystery we shall quote Mr. Gilbert's own words. After stating the efficiency of steam as above, and explaining that every impediment is supposed to be removed, he proceeds to say, that when this power of steam is applied through the medium of a piston acting in a cylinder of a steam engine, large deductions must be made to arrive at the practical duty, that is, of the weight actually raised.

The air pump is usually constructed of a size to require about one-eighth part of the efficiency.

Some imperfection in the vacuum cannot be avoided, and friction must exist to a considerable amount where bodies in motion have to confine an elastic vapour ready to escape through the smallest aperture, so that probably 30,000,000 would have exceeded the attainable limit of duty, but for two expedients, viz.

First, by causing the steam to act expansively after exerting its whole force through a certain part of the cylinder; and,

Secondly, by raising the temperature much above 212°

Machinery.

Natural efficiency increased by artificial means.

First, by working expansively.

Manufactures. of Fahrenheit, and thereby communicating to the steam a power beyond what is termed atmospheric strength. This, of course, requires more fuel, but not proportional to the increase of force.

To illustrate the first of these properties. Let AB, fig. 9, represent the portion of the cylinder through which the piston is urged by the entire force of the steam, and let its force be expressed by unity; and let the supply of steam from the boiler be cut off by the valve at r , when the piston has descended to B. Assume further that the piston has descended through the space x to B', urged by the expansive power or elasticity of the steam, the density of which will then be $\frac{1}{1+x}$; and assuming that densities and elasticities are

proportionate, $\frac{x'}{1+x}$ will be the fluxion of the efficiency,

and the efficiency itself equal to the fluent of this or to the nat. log. of $(1+x)$, and the efficiency of the whole stroke from A to B is, therefore, $1 + \text{nat. log. } (1+x)$, giving this very curious result, (*Phil. Trans.*) that when x is infinite, the efficiency is also infinite, or exceeding any assignable limit. When

$n = 1$ or the steam is shut off at a half stroke.	efficiency = 1.693
$n = 2$ or at one-third.	= 2.099
$n = 3$ or at one-fourth.	= 2.356
$n = 4$ or at one-fifth.	= 2.609
$n = 5$ or at one-sixth.	= 2.792

And to the latter extent, viz. $n = 5$, the principle has been attempted; but beyond this, notwithstanding the theoretical expression, it is not likely any practical advantage could be obtained, if it can be to this extent.

Mr. Gilbert, in stating these results, observes that several important circumstances are necessarily omitted in the investigation; namely:

1. The reduction of temperature, and, consequently, of elasticity, caused by rarefaction as the steam expands.
2. The increased relative effect occasioned by the reaction of the imperfect vacuum.
3. The increased relative burden of the air pump.
4. The relative increased friction.

So that, although this mode of working is highly advantageous, yet it is probable that, in practice, not more than from one-half to two-thirds of the cylinder can beneficially be occupied by expansive steam.

(143.) The second expedient, that of employing steam at a high degree of temperature, and, consequently, of pressure, would naturally suggest itself from the facts recorded in some preceding articles in this Chapter; namely, that a quantity of heat amounting to about 900 times that required to raise the temperature of a given weight of water one degree on Fahrenheit's thermometer, becomes latent in the conversion of that water into steam; and that an elevation of temperature of 40° of Fahrenheit above 212° , double the steam's elasticity, that 30° more treble it, and so on, see Table, Art. 125. And hence it would seem to follow that an increase of efficiency might be obtained almost ad libitum, by increasing the temperature of the steam; but in this reckoning the following most important circumstances were overlooked, till experience forced them into view: That the temperature of steam cannot be raised with a speed suitable to mechanical purposes in any other way than in contact with its water of generation; and that water heated above 212° sends off more steam,

Machinery. with a proportionate absorption of latent heat, increasing the density of the steam previously generated of atmospheric elasticity, so as about to double its power at 256° , but at an expense of fuel not much inferior to the power gained.

There is, however, a gain by adopting this principle of heating beyond 212° , and there is a gain by making the steam act expansively; and these are carried in the Cornish engines to a very considerable extent. We have seen that the natural efficiency of steam is from 40,000,000 to 50,000,000 of pounds raised a foot high with every impediment removed; and in many Cornish engines the working duty, after overcoming all impediments, amounts to 60,000,000, 70,000,000, and 80,000,000, and in one engine in particular, the duty effected by it for several days was 102,000,000, which is from two to two and a half times its natural efficiency.

(144.) *Condensation of steam.*—We have hitherto spoken of the generation of steam, its density, elasticity, and power of expansion, but another of its important properties remains to be described and investigated, its capability of rapid condensation. It has been already observed, that if the condensation of steam required as much time as its generation, or any very considerable time, its efficiency as a mechanical agent would be very inconsiderable; this was the defect with the Marquis of Worcester's, Morland's, and some other early engines; in fact, its capability of rapid condensation was not then understood, and the steam engine, in comparison with what it now is, may be said to have been powerless. When a substance colder than steam itself is put in contact with it, the steam condenses till the temperature of the cold body becomes the same as that of the steam, or till the whole mass of steam is condensed to a degree of elasticity corresponding to the temperature to which the cold body is raised by the heat of the steam, it being one of the properties of heat, already stated in the definitions, to restore itself to equilibrium; consequently, the colder the body is, or its temperature being the same, the greater its surface, the more rapidly the temperature of the hot body will be reduced, and in the case of steam, the more rapid its condensation. Consequently, in this process in a steam engine, the surface of the body through which the condensation is made should be as great, and its temperature as low as possible. Another quality the condensing body ought to possess, is that of being a good conductor of heat, whereby the process of condensation may be as rapid as possible. It may be readily demonstrated that if steam were to condense so as to lose only equal quantities of heat in equal times, and, of course, equal degrees of elastic force, half its power would be lost.

Water is a body particularly effective for this purpose: it may generally be obtained at a medium temperature; it is an excellent conductor of heat; it has great specific heat; and in the form of a jet may be made to present a very great cooling surface to the steam. The discovery of this effect of water, Savery states, was by an accident, while making some experiments with a Florence flask. This, however, is denied by Desaguliers, who says the discovery was made accidentally by Newcomen, with one of his early engines, by a little water having found its way through the piston into the receiver of the cylinder which produced a sudden and most extraordinary effect. However this may be, it is the capability of steam for rapid condensation on which depends the immense power of the steam engine.

Manufac-
tures.

It will be seen, however, in the following Chapter, that although water thus furnishes an excellent medium for the production of this effect, it is, like most other conveniences, attended with its inconveniences. All the water used for injection has to be again removed from the condenser; this water also brings in with it a certain portion of atmospheric air which must also be removed; and to effect these objects, an air pump, requiring considerable force, must be employed, which is a deduction of so much useful effect: moreover, in many cases a sufficient quantity of water for the purpose cannot be obtained, or not without considerable inconvenience.

This has led many ingenious men to endeavour to produce condensation without the injecting water, but hitherto with little success. A patent has, however, been lately obtained by Mr. Hall, of Basford, near Nottingham, which is said to have been tried with great success in several new engines, this is by exposing the steam to a great extent of pipes filled with water, or in which water is constantly passing, and which is said to produce the desired effect. By this means the condensed steam in the form of water is returned to the boiler, the steam regenerated and condensed always employing the same water, which (supposing even some waste in the process) must still be acknowledged is a great advantage. A somewhat similar contrivance, at least one for the same purpose, has been also recently proposed by Mr. Howard, jun., of the King and Queen Iron Works at Rotherhithe, in the patent for a steam engine without a boiler, described in a subsequent article.

Whatever success, however, may ultimately attend these engines, the process of condensing by injection will be practised to a great extent, and it will, therefore, be desirable to give a concise investigation of the circumstances which occur in this process.

Let W denote the weight of water used for injection, its temperature being t , and let T denote the temperature of the steam, its weight being w ; let also x be the temperature of the water after condensation. Then taking 1000° as the latent heat of steam.

$W(x - t)$ will be heat gained by the water, and $w(1000 + T - x)$ will be the heat given out by the steam; and as these must be equal, we have

$$W(x - t) = w(1000 + T - x).$$

Whence

$$W = \frac{w(1000 + T - x)}{x - t},$$

and

$$x = \frac{w(1000 + T + wt)}{W + w}.$$

To find the quantity of water necessary to produce condensation, the admitted temperature of the water in the condenser after condensation must be fixed; it is not easy to carry this lower than 100° : in low pressure engines the temperature of the steam is generally about 220° , and that of the injected water may be taken at 52° . Whence $x = 100^\circ$, $T = 220^\circ$, $t = 52^\circ$, wherefore

$$W = \frac{w(1000 + T - x)}{x - t} \text{ becomes}$$

$$W = \frac{w(1000 + 220 - 100)}{100 - 52} = 23\frac{1}{2}w.$$

So that to obtain the temperature of the water in the condenser at 100° , the quantity of injection water must be between twenty-three and twenty-four times as much

as the quantity of water requisite to fill the cylinder with steam at 220° . Now we have seen that a cubic inch of water will make about a cubic foot of steam of this elasticity or temperature, and therefore $23\frac{1}{2}$ inches will be required for every cubic foot of steam in the cylinder. According to Mr. Watt's practice he allowed a pint or $28\frac{7}{8}$ inch for this purpose.

In low pressure engines the temperature $T = 220^\circ$ is pretty constant, and $t = 52^\circ$ may also be supposed a fair medium temperature for the injection water; and substituting these as constants we shall have the ratio of W and w more simply expressed by

$$W = \frac{w(1220 - x)}{x - 52}.$$

Where by merely inserting different values of x , or different temperatures for the condensed water, we may obtain the ratio between W and w for all temperatures; and the capacity of the cylinder and quantity of condensing water being given, we, of course, readily obtain the quantity in question.

Thus, when the temperatures of the condensed water are as below, the ratio of W to w will be also as there expressed, viz.

$x = 100^\circ$	$W : w :: 23.3 : 1$
$x = 110^\circ$	$W : w :: 19.9 : 1$
$x = 120^\circ$	$W : w :: 16.3 : 1$
$x = 130^\circ$	$W : w :: 13.9 : 1$
$x = 140^\circ$	$W : w :: 12.7 : 1$
$x = 150^\circ$	$W : w :: 10.9 : 1$
$x = 160^\circ$	$W : w :: 9.8 : 1$
$x = 170^\circ$	$W : w :: 8.0 : 1$

And in like manner the proportions may be obtained for all temperatures. It appears, therefore, that the higher the temperature of the water in the condenser, the less injection water is required; but the elasticity of the steam in the condenser increases so rapidly, that it is highly desirable to reduce the water to the lowest possible temperature, when a sufficient quantity of cold water can be obtained. The more water is used, however, the larger the condenser must be, and the greater the power required to work the air pump, so that practical men here, as in most other cases, must be limited in their proportions according to circumstances. The most usual temperature aimed at is 100° , at which the elasticity of the steam is about equal to 2.08 inches of mercury.

Early History of the Steam Engine.

1st Period to 1769.

(145.) A knowledge of the expansive power of steam could not long have remained hidden from mankind after they had acquired the art of applying fire to culinary purposes, but it was probably a long time afterwards before the thought occurred of applying it to produce motion. The first indication we find of such an idea is by Hero of Alexandria, who described a contrivance for effecting this object, and of which he is generally considered the inventor.

This consisted of a caldron in which steam was generated by a concealed furnace; out of the former proceeded two arms, one hollow or tubular, the other solid; they ascended above the boiler and were there bent inwards, and between them was suspended, as on an axis, a hollow globe. The hollow tube or pipe being connected

Hero's application of steam to produce motion.

Manufac-
tures.

with the globe by a steam-tight joint, but still such as to admit freedom of motion; and the opposite side of the globe was connected with the fixed solid arm so as to admit of the free rotation of the ball. From the latter proceeded two short tubes bent at right angles with the axis, and opposite to each other in direction, from which the steam, generated in the boiler, and transferred to the globe, escaped, and by the resistance the vapour encountered from the atmosphere, the ball was put in rapid rotation.

Brancas's
proposition.

Early in the XVIIth Century, *i. e.* in 1629, another contrivance was published by an Italian Philosopher, Brancas. This, like the former, depended upon the elastic power of steam. It consisted of a close vessel of copper, representing the head of a negro filled with water. It was furnished with a small tube proceeding from the mouth, and seemed to be intended to give motion to a sort of wheel, which was impelled by the action of the steam or elastic vapour generated within. The Work in which this engine was first described, was published in 1629; it is exceedingly rare, but a fac simile of the engraving is given by Partington in his descriptive account of the steam engine, from an engraving in the possession of Colonel Colby of the Royal engineers.

These futile attempts for the production of motion and power by the operation of steam would scarcely deserve any attention, but that the importance of the present engine renders highly interesting every step, however remote, which appears to have in any respect contributed to the general march of invention in the progress of this noble Machine. The motions above described were most probably, in their effects, very little more than those which we are now enabled to produce by our electrical Machines, galvanic batteries, and magneto-electric apparatus, the origin or cause of the motion not being very dissimilar; *viz.*, the resistance offered by the air to the escape of a highly elastic fluid.

(146.) The expansive force of steam is doubtless one of the great principles on which the power of the steam engine as a mechanical agent depends, but a still greater, and without which the former would be of little avail, is its property of rapid condensation. If the progress of condensation were as slow as that by which its expansive power is developed, its mechanical efficiency would be very small; it was the discovery, therefore, of this property which must be considered as the first step towards the invention of the present steam engine. Some persons have thought that this discovery was made by the Marquis of Worcester, about the middle of the XVIIth Century, but it has been maintained with more reason that this author was only acquainted with the expanding power, and that nothing further is implied in his obscure remarks in his celebrated Work, *A Century of the Names and Scantlings of Inventions*, published without date at the time above referred to. The author died in 1663.

Marquis of
Worcester's
project of a
steam en-
gine.

Nothing can be more obscure and unintelligible than the notice which this mysterious writer has left of his invention, yet there can be no doubt he had obtained some extraordinary results by the power of steam, whether he availed himself of the condensing power or not. At all events, had he published what he had invented for the benefit of mankind, instead of enveloping the whole in mystery, for the purposes of personal vanity, he would have been entitled to the respect and veneration of his Country.

It is said that this nobleman, while confined in the Tower of London, was preparing some food on the fire

VOL. VII.

of his apartment, and the cover of the vessel having been closely fitted, was, by the expansion of the steam, suddenly forced off and driven up the chimney. This circumstance attracting his attention, led him to a train of thought, which terminated in this important discovery. But no figure has been preserved of his invention, nor, as we have good reason to suppose, any description of the Machine he employed, except what is given in the sixty-eighth article in the above-mentioned Work. We shall content ourselves, therefore, with extracting that article from the author's MS. preserved in the British Museum.

Machinery.

"An admirable and most forcible way to drive up water by fire; not by drawing or sucking it upwards, for that must be, as the Philosophers call it, *infra sphæram activitatis*, which is but at such a distance. But this way hath no boundary, if the vessels be strong enough; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three-quarters full of water, stopping and screwing up the broken end, as also the touch-hole; and making a constant fire under it, within twenty-four hours it burst and made a great crack; so that having found a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain stream, forty feet high: one vessel of water rarefied by fire driveth up forty of cold water. And a man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively, the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks." *Vide Harleian MSS.*, No. 2428.

(147.) We have said, speaking of this invention, that some have supposed that the Marquis of Worcester availed himself of the contracting property of steam; Mr. Tredgold, however, is not willing to admit that he possessed any knowledge of this principle, and has given a sort of engine such as he conceived might resemble the one indicated in the noble author's description. Tredgold says, p. 3. of his *Treatise on the Steam Engine*, This description puts it beyond a doubt, that the Marquis of Worcester knew that steam, heated in a close vessel, acquires an immense degree of force, and that this force could be effectively applied to raise water. The effect of condensation he does not appear to have been at all acquainted with, and, therefore, this mode of operation must have been exceedingly simple, and, probably, of the nature exhibited in pl. ix. fig. 6, where B is the boiler, C one of the vessels with a pipe to deliver the water to an elevated cistern D.

Probable
form of the
Marquis of
Worcester's
engine.

Pl. ix.
Fig. 6.

Now suppose the vessel C to be supplied from a cistern of cold water by a pipe, so that it would be filled on opening the cock E, and this cock being closed; if, when the steam in the boiler is of sufficient strength, the cock F be opened, the pressure of the steam on the water in C would cause it to ascend from C, through the pipe *a*, into the cistern D. The vessel C being emptied, and the cock F being shut, it would refill with water on opening the cock E. Another vessel C, and its cocks and pipes, are necessary to complete the species of water engine indicated by the description, which may be conceived to be on the other side of the boiler.

Such a mode of raising water would be most expensive from the quantity of condensation when the steam came in contact with cold water; but it was fully capable of producing the quantity of effect mentioned, for it is

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Manufac-
tures.

only equivalent to raising twenty cubic feet of water, or 1250 pounds, one foot high by one pound of coal, or about the 200th part of the effect of a good steam engine. Hence it appears that to the Marquis of Worcester must be ascribed the first invention and trial of a practical mode of employing steam as a prime mover, and of applying it to one of those great purposes for which it has been so useful to society.

(148.) In 1683, a scheme for raising water by the agency of steam was offered to the notice of Louis XV. by an ingenious English mechanic, Sir Samuel Morland. He was presented to the French Monarch in 1682, and in the course of the following year his apparatus is said to have been actually exhibited at St. Germain. The only notice of this plan occurs in the collection of MSS. to which we have already alluded, and forms the latter part of a very beautiful volume, containing about thirty-eight pages, and entitled *Elévation des Eaux par toute Sorte de Machines, réduite à la Mesure, au Poids, et à la Balance. Présentée à sa Majesté très-Chrétienne par le Chevalier Morland, Gentilhomme Ordinaire de la Chambre privée, et Maître des Mécaniques du Roy de la Grande Brétaigne*, 1683.

Morland's
steam en-
gine

The MS. is written upon vellum, richly illuminated, and the part which has reference to the steam engine occupies only four pages, commencing with a separate title, &c. It is also accompanied by a Table of the sizes of cylinders, and the account of water to be raised by a given force of steam. This curious Memoir forms an important link in the chain of historical evidence, we shall, therefore, offer no apology for presenting a translation of it to the notice of the reader.

"*The Principles of the new Power of Fire, invented by Chevalier Morland in the Year 1682, and presented to his Most Christian Majesty 1682.*"

"Water being evaporated by the force of fire, the vapour shortly acquires a greater space (near two thousand times) than the water, occupied before; and was it to be always confined, would burst a piece of cannon. But being well regulated according to the laws of gravity, and reduced by Science to measure, weight, and balance, then they carry their burdens peaceably, (like good horses,) and thus become of great use to mankind, particularly for the elevation of water, according to the following Table, which marks the number of pounds that may be raised 1800 times per hour by cylinders half full of water, as well as the different diameters and depths of the said cylinders."

TABLE of the Diameter and Length of Steam Cylinders; with the Number of Pounds Weight to be raised.

Cylinders.		Pounds Weight to be raised.
Diam. in Feet.	Depth in Feet.	
1	2	15 lbs.
2	4	120
3	6	405
4	8	960
5	10	1875
6	12	3240

TABLE continued.

Machinery.

Number of Cylinders which are 6 Feet in Diameter and 12 Feet in Depth.	Pounds Weight to be raised.
1	3240 lbs.
2	6480
3	9720
4	12960
5	16200
6	19440
7	22680
8	25920
9	29160
10	32400
20	64800
30	97200
40	129600
50	162000
60	194400
70	226800
80	259200
90	291600

(149.) In 1698, three years after Sir Samuel Morland died, Dr. Papin, a Frenchman, suggested the idea of employing the expansion and condensation of steam to form a partial vacuum under a piston for raising water; and if, therefore, the condensation did not form any part of the last two schemes, we must admit that this author made an important step towards the present engine. In this contrivance, the pressure of the atmosphere on the upper side of the piston formed the moving power; but the arrangement proposed was impracticable, as the fire was to be alternately applied to and removed from the cylinder, and the expansion of it by heat was to raise the piston, and its contraction by cooling, when the fire was removed, was to cause a partial vacuum, and, consequently, the descent of the piston was to be produced by the pressure of the atmosphere. Here, at least, we have an intelligible process; for although it seems doubtful whether, according to this plan, any useful effect could have been produced, yet the principle of the atmospheric engine is here clearly indicated; and the step between this and the next proposition by Savery, was by no means difficult.

(150.) In 1699, M. Amontons published a description of a Machine, which he called a *fire-wheel*, designed to be moved by the spring of air when expanded by heat, and afterwards condensed by contact with cold water. The continual access of heated air to water would ultimately render the air saturated with vapour; but even then it would not be more than an air engine, and a very indifferent one, being exceedingly complex. In this wheel, one part of the circumference was exposed to the heat of the furnace, and the other to a stream or current of cold water; and by means of close buckets communicating with each other, which were placed round the circumference, the steam produced into the bucket on one side of the wheel drove the water into the buckets on the other side; so that one side of the wheel was always much heavier than the other, and must, therefore, turn round, and thus be made to execute some work. It is very doubtful, from the complicated nature of this Machine, whether, if the author had lived, it could ever have been made available to any useful purpose: at all events, his death caused it to be wholly neglected, and this was also the case with another construction of about this date, by M. Deflander, who also presented a steam

Fire wheels
by Amon-
tons and
Deflander.

Manufactures. wheel to the Academy of Sciences, being himself a Member of that learned body.

Savery's patent for a steam or fire engine. (151.) In 1698, letters patent were granted to Captain Thomas Savery, (after his having erected, according to Dr. Robison, several Machines of this kind,) for securing to him the right of this invention.

In 1699, Savery exhibited a model of his engine before the Royal Society, and the experiments he made with it succeeded to the satisfaction of the Fellows. (See *Ab. Phil. Trans.* vol. iv. p. 398.) The figure, as represented in the *Philosophical Transactions*, is very obscure; but a more intelligible account is given in this author's Work, called the *Miner's Friend*, first published in 1699, and again in 1702. A neat diagram, and a very plain description of Savery's engine, is also given in Dr. Robison's *History of the Steam Engine*; see vol. ii. of his works by Brewster, from which the following is extracted.

Description of the engine. Pl. ix. Fig. 7. A (pl. ix. fig. 7) represents a strong copper boiler properly built up in a furnace. There proceeds from the top a large steam pipe B, which enters into the top of another strong vessel R, called the receiver. This pipe has a cock at C, called the steam cock. In the bottom of the receiver is a pipe F, which communicates side-wise with the rising pipe K G H. The lower end H of the pipe is immersed in the water of the pit or well, and its upper part K opens into the cistern into which the water is to be delivered. Immediately below the pipe of communication F there is a valve G, opening when pressed from below, and shutting when pressed downwards. A similar valve is placed at I, immediately above the pipe of communication. Lastly, there is a pipe E D, which branches off from the rising pipe, and enters into the top of the receiver. This pipe has a cock D, called the injection cock. The mouth of the pipe E D has a nozzle pierced with small holes, pointing from a centre in every direction. The keys of the two cocks C and D are united, and the handle g h is called the regulator.

Let the regulator be so placed that the steam cock C is open, and the injection cock D shut; put water into the boiler A, and make it boil strongly. The steam coming from it will enter the receiver, and gradually warm it, much steam being condensed in producing this effect. When it has been warmed so as to condense no more, the steam proceeds into the rising pipe, the valve G remains shut by its weight, the steam lifts the valve I, and gets into the rising pipe, and gradually warms it. When the workman feels this to be the case, or hears the rattling of the valve I, he immediately turns the steam cock so as to shut it; the injection cock still remains shut, (at least we may suppose this for the present.) The apparatus must now cool, and the steam in the receiver collapse into water. There is nothing now to balance the pressure of the atmosphere; the valve I remains shut by its weight, but the air incumbent on the water in the pit presses up this water through the suction pipe H G, and causes it to lift the valve G, and flow into the receiver R, and fill it to the top, if not more than twenty or twenty-five feet above the surface of the pit water.

The steam cock is now opened. The steam which, during the cooling of the receiver, has been accumulating in the boiler, and acquiring a great elasticity by the action of the fire, now rushes in with great violence, and pressing on the surface of the water in the receiver, causes it to shut the valve G, and open the valve I by its

weight alone, and it now flows into the rising pipe, and would stand on a level if the elasticity of the steam were no more than what would balance the atmospherical pressure. But it is much more than this, and therefore it presses the water out of the receiver into the rising pipe, and will cause it to come out at K, if the elasticity of the steam be sufficiently great. In order to ensure this, the boiler has another pipe in its top, covered with a safety valve V, which was Papin's invention, and which is kept down by a weight W, suspended on a steel-yard L M. This weight is so adjusted that its pressure on the safety valve is somewhat greater than the pressure of a column of water as high as the point of discharge K. The fire is so regulated, that the steam is always issuing a little by the loaded valve V. The workman keeps the steam valve open till he hears the valve I rattle. This tells him that the water is all forced out of the receiver, and that the steam is now following it. He immediately turns the regulator which shuts the steam cock, and now, for the first time, opens the injection cock. The cold water trickles at first through the holes of the nozzle f, and falling down into the steam, begins to condense it; and then its elasticity being less than the pressure of the water in the pipe K E D f, the cold water spouts in all directions through the nozzle, and quick as thought produces a complete condensation. The valve G now opens again by the pressure of the atmosphere on the water of the pit, and the receiver is soon filled with cold water. The injection cock is now shut, and the steam cock opened, and the whole operation is repeated; and so on continually.

(152.) After the step thus made by Savery, Papin published, in 1707, a small Treatise on the Steam Engine, in which he candidly acknowledges that Savery's scheme was not borrowed from any thing done in Germany. And it does not appear by this Work that he had at all prosecuted his original idea since 1698, at least not with any useful results. In 1705 he saw the engraving of Savery's engine, and in 1707 proposed his new construction, which, to do justice to his claims, it will be proper to describe, as he gives it, after knowing what Savery had effected.

It consisted of a boiler B, (fig. 8,) provided with a safety valve V; and a cylinder G H, connected to the boiler by a steam pipe S. The cylinder was closed at the top, and contained a floating piston P; and the base of the cylinder terminated in a curved tube T, which ascended into a cylinder M. The bent tube had a pipe Y from a reservoir of water communicating with it, and it was provided with a valve at r. Now suppose the cylinder G H to be filled with cold water by the pipe Y from the reservoir, and the boiler to contain strong steam; by opening the cock E, the steam would be admitted, and, pressing on the floating piston P, cause the water to ascend into the cylinder M; its return is prevented by the valve K, and the steam cock E being shut and the cock R opened, to let the condensed steam escape at the pipe R, the water from the reservoir refills the steam cylinder through the pipe Y, which is thus ready for repeating the operation. The water raised is to be directed to any useful object by the pipe D.

(153.) It is much to be regretted, that the question of the invention of the steam engine has led to a national controversy between the French and English: the one maintaining the claim of Papin, and the other that of the Marquis of Worcester. We believe we are quite free from any prejudice on this head, and will endeavour

Claims to the invention of the steam engine examined.

Manufac-
tures.

before entering upon a description of the further improvements, to pass in review the claims of the different authors to this time.

The Marquis of Worcester did certainly previous to 1663, the year of his death, throw out suggestions relative to the construction of some engine for raising water by the force of steam; and, according to his assertion, had actually constructed one, but his account is so mystified, that no one could benefit from it; and his only merit seems therefore to be, his having called the attention of others to the subject.

Sir Samuel Morland undoubtedly executed an engine of this kind in 1682, but unfortunately all traces of its actual form are unknown; and it seems to have excited but little attention, although from the statement he makes, of the space a quantity of water will occupy in the form of steam, which differs but little from the truth, it is evident that he had pursued the subject far beyond the Marquis of Worcester, to whom, however, he was in all probability indebted for his idea of the engine.

The next claimant is Dr. Papin, in 1698; but following the other two by some years, it seems absurd to give him the honour of the invention, as it is also to deny that he made some useful additions. The adoption of the safety valve and the floating piston were undoubtedly introduced by this author.

Papin and Savery were exercising their ingenuity so nearly at the same time, that nothing can be said as to priority; their merits can only be judged of by the results of their labours, and in this respect Savery has the greater claim. Probably at that time, as more recently, England furnished better opportunities for the exercise of the profession of the engineer than France or Germany, and every new engine erected most likely pointed out some new improvement, which gave to Captain Savery an advantage of which he availed himself; and since that time, England may almost consider the steam engine as a national Machine; to which she is largely indebted for her power and distinction amongst nations.

(154.) At present we have spoken only of Captain Savery's engine, as improved by himself; but as is said above, every new trial discovered defects, and suggested new improvements, not only to himself, but to others. The expense also attending the raising of water from the mines at that time, and the prospect which these several attempts offered, of benefiting the proprietors of those works, were powerful motives to the prosecution of further researches; and to this stimulus we are indebted for a very important change in the character of the engine by Newcomen, a smith, or ironmonger, at Dartmouth, who in conjunction with John Cawley, of the same place, and Captain Savery himself, obtained letters patent for the invention in 1705. The novelty in this construction consists in condensing the steam below an air-tight piston in a cylindrical vessel, having an open top; and the idea was very probably taken from the project of Papin's floating piston, but the mode of effecting the object was entirely different.

This engine is represented in (pl. x. fig. 1,) in which the injection water is seen issuing out of the pipe into the cylinder in the form of a jet. This important step is said by Desaguliers to have been the result of accident. According to this author, the condensation was originally made by the application of cold water on the outside of the cylinder, as first practised by Savery, while the piston was kept steam tight by water above floating on its

surface; and that while thus working an accidental hole in the piston having admitted a small quantity of water to fall into the cylinder, it caused a rapid condensation, and an equally rapid motion to the engine, a circumstance of which they were not slow to avail themselves, by giving to the injection cock the situation shown in the figure. This engine has received many improvements since this time; we are not, however, intending to describe the more modern atmospheric engine, but simply the improvements as far as they were carried by Newcomen himself. Here B represents the boiler, with its furnace for producing steam, and at a small height above the boiler is a steam cylinder C, of metal, bored to a regular diameter, and closed at the bottom, the top remaining open. A communication is formed between the boiler and the bottom of the cylinder, by means of a short steam pipe S. The lower aperture of this pipe is shown shut by the plate *p*, which is ground flat, so as to apply very accurately to the whole circumference of the orifice. This plate is called the regulator or steam cock, which turns horizontally on an axis *a*, which passes through the top of the boiler, and is fitted steam tight, and has a handle *b*, by which it is opened and shut. A piston P is fitted to the cylinder and rendered air tight by a packing round its edge of soft rope, well filled with tallow to reduce the friction, and its upper surface is kept covered with water to render it air tight. The piston is connected with the rod P A, which is suspended from the upper extremity D of the arched head of the lever by the chain A, this lever, or working beam, turning on the gudgeon G. The beam has also a similar arched head E F, at its other extremity, for the pump rod H, which receives the water from the mine. The end of the beam to which the pump rod is attached, is made to exceed the weight and friction of the piston in the steam cylinder; and when the water is drawn from such a depth, that the pump piston is too heavy for this purpose, counterpoise weights must be added at I, till the piston will rise in the steam cylinder at the proper speed. At some height above the top of the cylinder is a cistern L, called the injection cistern, supplied with water from the forcing pump R. From this descends the injection pipe M, which enters the cylinder through its bottom, and terminates in one or more small holes at N. This pipe has a cock called the injection cock, fitted with a handle. At the opposite side of the cylinder, a little above its bottom, there is a lateral pipe, turning upwards at the extremity, and provided with a valve at V, called the snifting valve, which has a little dish round it to hold water for keeping it air tight.

There proceeds also from the bottom of the cylinder a pipe Q, of which the lower end is turned upwards, and is covered with a valve *v*; this part is immersed in a cistern of water called the hot well, and the pipe itself is called the eduction pipe. To regulate the strength of the steam in the boiler, it is furnished with a safety valve, constructed and used in the same manner as that of Savery's engine, but not loaded with more than one or two pounds on the square inch.

The mode of operation remains to be described. Let the piston be pulled down to the bottom of the steam cylinder, and shut the regulator or steam valve *p*, then the piston will be kept at the bottom by the pressure of the atmosphere. Apply the fire to the boiler till the steam escapes from the safety valve, and then on opening the steam regulator, the piston will rise by the joint effect of the strength of the steam and action of the

Machinery.

Newco-
men's ori-
ginal en-
gine.
Pl. x.
Fig. 1.

Manufac-
tures.

excess of weight on the other end of the beam. When it arrives at the top of the cylinder, close the regulator *p*, and by turning the injection cock *O*, admit a jet of cold water, which condenses the steam in the cylinder, forming a partial vacuum, and the piston descends by the pressure of the atmosphere raising water by the pump *H* from the mine. The air which the steam and the injecting water contains is impelled out of the snifting valve *V*, by the force of descent, and the injection water flows out at the eduction pipe *Q*, and by repetitions of the operations, of alternately admitting steam and injecting water, the work of raising water is effected.

According to Desaguliers, *Exp. Phil.* vol. ii. p. 533. the operation of opening and shutting the cocks was done by hand till a boy named Humphrey Potter, who was employed for this purpose, in order that he might indulge in play, contrived, by means of cords and lines attached to the working parts of the Machinery and to the cocks, to make the engine perform this operation itself; the first step yet made towards rendering the Machine self-regulating, a principle which has been since carried perhaps to its utmost possible limits.

We have now traced the steam engine from its earliest date to the year 1712, at which time it had arrived at the state above described; and it must have been a great source of satisfaction to Savery to have himself witnessed and superintended the engine from its first effective working form, till it had attained this degree of perfection, although he was doubtless entirely indebted to Newcomen for the latter improvements. The great principle of the steam engine was now established, and only perfection of workmanship, and a better knowledge of the nature of steam, were requisite to render it competent to the discharge of very important duties.

We have, therefore, no longer to inquire into the history of the invention, but simply to illustrate the several improvements which have since been introduced into its construction; although the very great change the engine underwent in the hands of Mr. Watt seems to furnish a distinct epoch in its history. We shall accordingly treat the subject in this way, by first pointing out the improvements and suggestions which were made between this date, 1712, and 1769, when the latter philosophical inquirer undertook his earliest experiments on the subject.

In 1717 Henry Beighton, F. R. S. made several improvements in the connecting parts of Newcomen's engine, and was the first who attempted to reduce the power of the engine to computation.

Improve-
ments by
Beighton.

High pres-
sure engine
by Leupold.

Fig. 2.

(155.) In 1720 Leupold, the learned author of a Work on various mechanical subjects, proposed an entire new construction, which is now called the high pressure principle, the engine being worked by the pressure of steam acting against the atmosphere. This principle may be thus described. Over the boiler *B* (fig. 2) is placed two cylinders *CC*, fitted with steam-tight pistons *pp*. A four way steam cock *S* is placed between the boiler and cylinders, so as alternately to admit steam into one cylinder, and let it out from the other. The piston, by the admission of strong steam from the boiler below it, is raised, and depresses the other end of a lever connected to the rod of a plunger of a pump, which causes the water to rise through the pipe, and by the alternate action of the steam in the two cylinders, a continual stream of water is raised. Thus the first rude notice of the principle of employing high pressure steam upon a piston was given.

The four way cock employed in this engine, and since

so much in use, is also extremely neat, and was, in all probability, the invention of this ingenious writer.

(156.) The next writer of particular note on the subject of steam engines is Jonathan Hulls, who, so early as 1736, obtained a patent for applying the power of steam for the purpose of propelling vessels; an application of its power which has since worked such wonders in navigation. The title of the Pamphlet in which Hulls's invention or proposition is contained is, *A Description and Draught of a New Invented Machine for carrying Vessels or Ships out of or into any Harbour, Port, or River against Wind or Tide, or in a Calm*. The extraordinary progress of steam navigation within the last twenty years, and its still increasing importance, have led to different claimants for the honour of so important an invention; and this has brought to notice this old Pamphlet, which was very scarce, and probably the few copies saved, which establish the claims of Hulls, were preserved rather by accident than by any particular value set upon them by their possessors. The method is certainly complicated, and perhaps scarcely practicable; yet as the first idea of such an application of the power of steam, it is as a historical fact extremely curious and interesting. It appears to have altogether failed at that time, either for want of encouragement, or from the inefficiency of the apparatus.

Machinery.

Hulls's pa-
tent for
steam boats

(157.) It has been stated that a boy, Humphrey Potter, had contrived a means of making the engine open and shut its own cocks, and that this idea was rendered more permanent by Beighton. Other methods were, however, afterwards proposed by Gensanne, a Frenchman, and afterwards by De Moura, a Portuguese, who sent a model of his method to the Royal Society, which is described by Smeaton in the *Phil. Trans.* for 1751. See also Abridgement of the same, vol. x. p. 252. Subsequent improvements have superseded this contrivance, the general description of which will therefore suffice for this place.

Gensanne's
engine.

"The engine," Mr. Smeaton observes, "consists of a receiver, a steam and an injection cock, a suction and a forcing pipe, each furnished with a valve, with a boiler, which, on account of its bulk and weight, is not sent with the rest; but as it may be of the common globular shape, and having nothing particular in its construction, a description of it will not be necessary, as also the rest of those parts already mentioned which being essential to every Machine of this kind, a further account of them may be dispensed with. What is peculiar to this engine, is a float within the receiver, composed of a light ball of copper, which is not loose in it, but fastened to the end of an arm, made to rise and fall by the float, while the other end of the arm is fastened to an axis, and, consequently, as the float moves up and down, the axis is turned round one way or the other. This axis is made conical, and passes through a conical socket, which last is soldered to the side of the receiver. On one of the ends of the axis, which projects beyond the socket, is fitted a second arm, which is also moved backward and forward by the axis, as the float rises or falls. By these means, the rising or falling of the surface of the water within the receiver communicates a correspondent motion to the outside, in order to give proper motions to the rest of the gear, which regulates the opening and shutting of the steam and injection cocks, and serves the same purpose as the plug-frame, &c. in Newcomen's engine."

(158.) Upto this time, 1741, although various improve-

Manufac-
tures.

First scien-
tific inquiry
into the
power of
steam by
Payne.

ments had taken place in the working parts of the atmospheric engine of Newcomen, yet nothing like scientific principles had been employed to ascertain the actual force of the powerful agent by which it was put into motion; but in this year Mr. J. Payne undertook an investigation of this kind, and published an account of his experiments in the *Phil. Trans.* for 1741. See Abridgement, vol. viii. p. 518. Unfortunately, he did not employ a thermometer, and, therefore, his results are not so accurate as they might otherwise have been: they, however, led the way to further researches, and were very ingenious. He procured a copper globe of twelve inches diameter, having two cocks fitted to it and a small valve. The vessel thus prepared was hung over a large vessel, in which water was rarefied into steam, and by a pipe the steam was admitted at one of the cocks into the globe, and the other being also open, the steam being allowed to blow through, forced out the air that was in the globe, and supplied its place, when both cocks were suddenly shut, and the globe taken down and hung over a vessel of cold water with the lower cock immersed in water. The cock was opened under water, on which the water rushed violently into the globe till it had supplied the vacuum, when the cock was again shut, and the globe, with the water, was put in the scales and found to weigh 713 oz. which, taken from 727 oz., the whole weight before, there remains only 14 oz., the difference, from which he inferred that all the air was nearly excluded out of the globe by the steam. He again excluded the air out of the globe with steam as before, and both the cocks being closed, with the globe full of steam, he put the globe in the scales and it weighed 202.5 oz. He then opened one of the cocks and let in the air, and by adding weight in the other scale it was found to weigh 203 oz., which showed that the weight of the air the globe contained was 5 oz., or 218.75 grains. The globe being filled with steam as before, and condensed with cold water on the outside of the globe, and the metal again made very dry, and the air let into the globe, the water from the condensed steam was found to weigh 96 grains. It is worthy of remark here, that this gives the density of steam at 212° , or that of air at 60° , as 96 : 218.75, or as 0.44 : 1. The true density of steam at 212° , is nearly as 0.48 : 1.

The globe was now filled with steam as before, but not knowing the effect of temperature, he continued the globe longer with the steam passing through it, by which it acquired a greater degree of heat; for he had found by these experiments, that the least degree of cold less than the steam, would condense a part of it again into water, and hence the quantity could not be ascertained which would exclude the air out of a given space, which was the chief end of the experiment. In this experiment he succeeded in excluding the air with less steam; for, on weighing the globe, when the steam was condensed, the air let in, and all cold, it was found the weight of the water condensed from the steam was only about forty-eight grains, which filled, when converted into steam, 925 cubic inches of space, so as to exclude nearly all the air. From which he concluded that one cubic inch of water will form 4000 inches of steam. To admit of comparison the temperature should have been observed, as there is little doubt that the steam was so rarefied by heat as to cause this result.

Mr. Payne also attempted to introduce a new mode of generating steam: this apparatus consisted of a cast-iron vessel of the figure of the frustrum of a cone, its

diameter at the bottom being four feet, with a semi-globular end of copper about five feet and a half diameter. In the inside a small vessel was inserted, which Payne called a *dispenser*, which vessel had pipes round the sides fixed to it; the bottom rested on a central pin, on which it revolved, so as to spread the water it received from above through an iron pipe. The end of this pipe passed up through the head, and was enclosed very tightly, but so as to be easily moved with a circular motion, whereby the water might be dispersed or showered round on the sides of the red-hot cone, or ignited vessel, in a very exact manner. From experiment he states,

1. That a pot or vessel, of the size and shape here mentioned, will, being kept to a dark red heat and the water regularly dispersed, rarefy or expand fifty gallons of water, wine measure, per hour.

2. That a cubic inch of water will make in practice 4000 inches of steam; or that the elastic steam of one cubic inch of water is sufficient to exclude the air out of a vessel which is in content 4000 inches. This, as said above, must have been at a high temperature.

3. That the above fifty gallons will produce 46,000,000 cubic inches of elastic steam per hour, which is per minute 770,000.

4. That the second pot or vessel (there being two in his Machine) will rarefy or expand forty gallons of water, wine measure, per hour, and will produce 36,960,000 cubic inches of elastic steam per hour, which is per minute 616,000 inches.

5. That both being united together, make 1,386,000 cubic inches of steam every minute, for 346 inches of water.

6. That by an experiment made by a fire-engine, forty gallons of water per hour, made into elastic steam in this method, will effectually give motion to a twenty-four-inch cylinder fire-engine.

7. That by true experiments made at Wedgbury and Newcastle on Tyne, 112 pounds of pit coal will and are sufficient in this method to expand or rarefy ninety gallons of water per hour into an elastic steam or vapour.

8. That by the best accounts and observations he could get and make, they consume under their boilers, to make the same quantity of steam, three hundred weight of pit coal in working a fire-engine one hour.

9. That ninety-five gallons of water per hour, expanded or rarefied into steam, will work a thirty-six-inch cylinder engine.

From these observations Mr. Payne concluded that this invention would save at least sixty per cent. in pit-coal to work a fire-engine, according to the work at that time effected by the usual operation.

These results are near the truth of what may be done, but the method has no advantages, and the apparatus soon fails. It is a duty, however, to an ingenious man to record his attempts to establish useful truths even when he fails in his object. It shows the state of knowledge at the time on these subjects, and it saves others from repeating useless experiments. The mode of generating steam we have just described has been more than once revived lately.

(159.) This scientific examination, however defective, of the power of steam and of the means of generation, was soon followed by other researches, and first by Mr. Francis Blake, F.R.S., who, in 1751, undertook an investigation relative to the best proportions for steam engine cylinders of given content, which was published in the *Phil. Trans.* for that year. See also Abridgement of *Phil. Trans.* vol. x. "It is evident," the author observes,

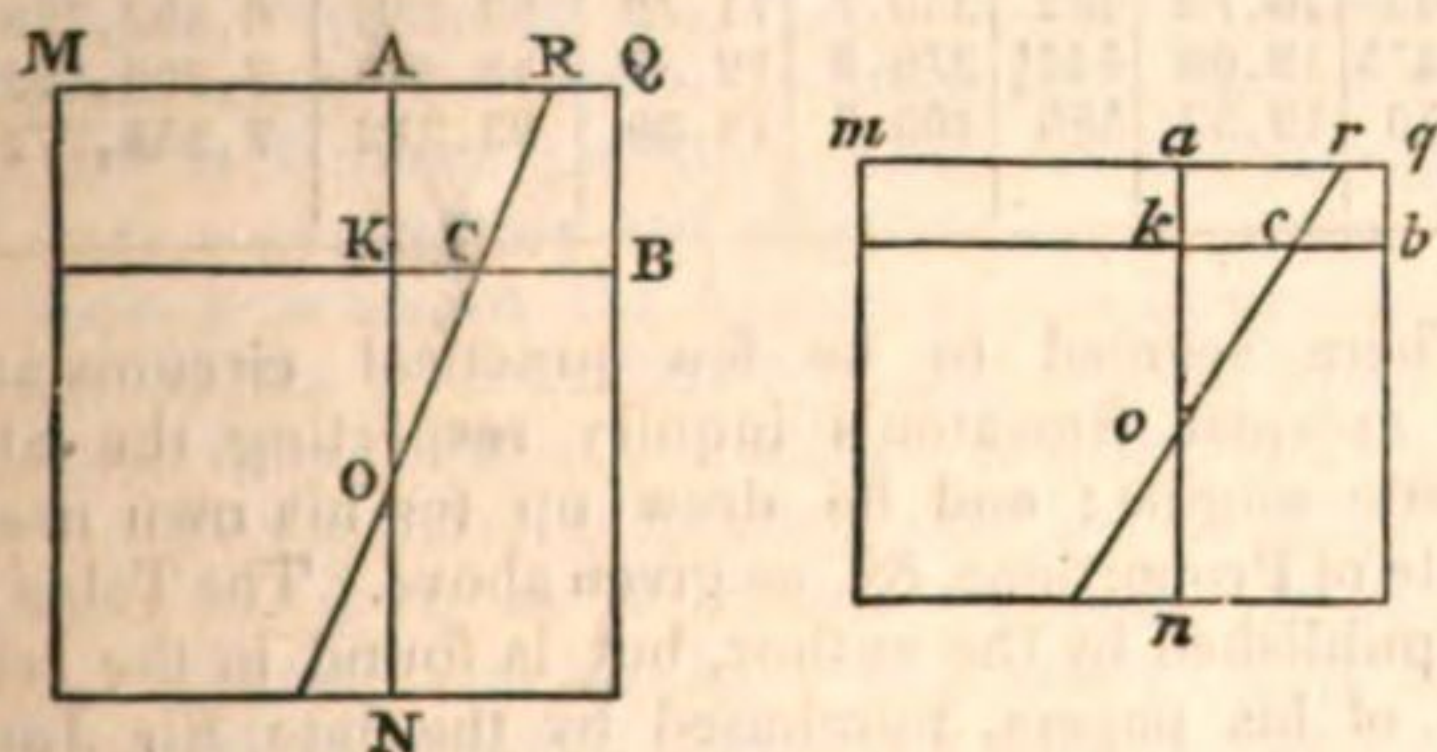
New mode
of generat-
ing steam
by the
same.

Machinery.

Manufac-
tures.

" in the first place, from a general law of Mechanics, that the content of the cylinder remaining the same, the quantity of water discharged at each lift will in all cases be equal, by only adjusting the distance of the centre of the piston from the fulcrum of the balance. It will be granted also that the excess of the column of atmosphere above that of the water, is a weight on the piston, driving it to a depth of about five feet, by the present construction, within the cylinder, acceleratedly, till friction and an impediment from the steam, which remains in the cylinder, even after the jet d'eau, and is increased in elasticity while its bounds are diminished, shall equal the accelerative force; and that then again the piston is retarded the rest of the way. It may be convenient to remark too, that if the rarefaction be so complete that the descent would be greater than the construction admits of, the retardation is augmented by an arm of the balance pressing on springs. But to say nothing of friction here, we can, notwithstanding this diminution of force by the remainder of steam within the cavity of the cylinder, demonstrate the ratio of the velocities, and the times of descent of the pistons, in cylinders of unequal altitudes, to be exactly the same as if the resistance was nothing; whence we shall without difficulty arrive at the same conclusion in this matter.

M N, in the annexed diagram, is the working part of a steam engine cylinder, of the usual height, equal in diameter to a shorter one m n; and the rarefaction in both of them being supposed the same, A Q = a q, R Q = r q, and A R = a r, may represent the excess of the atmosphere's weight above the column of water, the resistance to the pistons from the remainder of the steam, and the effective force respectively, e g, at the beginning of the descent.



Take then every where $a k : A K :: a n : A N$, and at all similar positions the resistance $b c$ of $m n$, and force $k c$ on its piston, will be equal to the resistance $B C$ of $M N$, and force $K C$ on its piston, and by well known principles we have $\sqrt{a k c r} : \sqrt{A K C R} ::$ celerity in k : celerity in K . But these areas being evidently as the corresponding parallelograms $k q$ and $K Q$, and these again as their heights, the celerities generated are in the subduplicate ratio of $a k : A K$, as if the resistance had been nothing; and by an obvious reasoning from the said proposition, the times also appear to be in the above-mentioned ratio, which ratio is not in any way varied, though the resistance prevails from the intersecting points o .

Now, to apply what has been said to the business in

hand: if T W be a cylinder of equal content with the cylinder M N, the quantity of water delivered by both will, as a consequence of the fundamental law of Mechanics observed above, be the

same at each lift. But the cylinder T W is no higher than $n m$, and therefore their

rarefactions are equal; hence by what has been proved with regard to the times, the time of the piston's descent in T W will be to that of the piston's descent in M N : $\sqrt{E W} : \sqrt{A N}$; whence in any given time the broad cylinder T W will perform more than the longer one M N of equal content, and that in the ratio of their diameters; for $F E^2 \times E W = M A^2 \times A N$, and $E W : A N :: M A^2 : E T^2$, consequently $\sqrt{E W} : \sqrt{A N} :: M A : T E$. The friction too is diminished with the slowness of the motion, because the periphery increases in a less ratio than does the area of a circle.

The result of the whole then is in favour of the broad cylinder; and still the broader the better; for unless some mechanical considerations should limit the problem, it is evident, in a geometrical sense, that there is no limitation. A disadvantage might arise perhaps to the effect of the jet d'eau from thus increasing the breadth; which, however, would probably be remedied by a number of these jets: but be that as it may, it is certain that to augment the diameters, and diminish the lengths of the smaller kind of cylinders now used, could have no such inconvenience, nor fail of being attended with an augmentation of force.

(160.) The next writer and practical operator in the improvement of the atmospheric engine, and who forms as it were the link which connects the first with the second epoch of the history of the steam engine, was the celebrated Smeaton, who erected several atmospheric engines, and brought them to a degree of perfection which has scarcely been exceeded in later times, principally, however, by a more judicious proportioning of the several parts to each other than had been before practised. and not by any alteration in the nature of its action. Having been called upon to erect several large engines of this kind, he found at first that he had to struggle with many difficulties, and they did not in all cases answer his expectation, sometimes requiring much more fuel than he had reckoned upon, and at others falling short of their anticipated duty; circumstances which led him to undertake the construction of an experimental engine, and which was also the first portable steam engine.

In this engine the fire-place was formed wholly within the boiler, and the arch ends of the beam he employed were segments of a wheel of 6.2 feet in diameter, with a chain communicating the motion from the piston to the pump rod; the diameter of the cylinder was 18 inches, its area in circular inches having been of course 324 inches; and allowing 7 pounds to the circular inch, which such a cylinder, he remarks, would very well carry, we have 2268 pounds for the whole pressure upon it. The length of its stroke was 6 feet, of which strokes it made 10 per minute, so that its duty was $2268 \times 6 \times 10 = 136,080$ pounds raised a foot high per minute, which he called a six-horse engine, reckoning the horse power 22,680 pounds, nearly as we stated it in Art. 2. It was not, however much more than a four-horse power according to the usual estimate. With this engine Mr. Smeaton made a number of experiments greatly diversified in their character, and thereby calculated to furnish every requisite information relative to this description of engine. From these experiments he deduced a variety of important proportions and results, the particulars of which are given in the following Table; and these proportions he afterwards followed in the construction of several first-rate engines, some of them exceeding one hundred horses' power.

Machinery

Smeaton's
improvements.

Manufactures.

TABLE of the Proportions of the Parts of an Atmospheric Engine founded on Experiments by Mr. Smeaton.

Machinery.

Cylinders.			Strokes.		Journey per Minute.	Boilers.		Diameter of Steam-pipe.	Square Hole for Jet of Injection.	Injection water per Stroke.		Boiler's Feed per Stroke.	Coals per Hour.	Pumpage.	Great Product per Minute.	Effect per Minute of one Bushel per Hour.
Diameter.	Square of Diameter.	Area in Square Inches.	No.	Length.		Centre Diameter.	Fire Surface.			In Ale Gallons.	Cyl. Inch Ft.					
Inch.	Cir. In.	Sq. In.		Ft. In.	Feet.	Ft. In.	Sq. Ft.	Inches.	Inches.			Cub. In.	Bushels.	Cyl. Ft. In.		Per Min.
12	144	113	16½	4 0	66	6 0	37½	2.50	.33	.6	18	12.7	.74	2.592	.171,072	231
14	196	153	16½	4 2	67.71	6 6	44	2.78	.375	.76	23	15.9	.91	3.528	.238,881	263
16	256	201	16	4 4	69.3	7 0	51½	3.06	.42	.93	28	19.7	1.11	4.608	.319,488	288
18	324	254	15½	4 6	70.88	7 6	58½	3.35	.47	1.13	34	23.9	1.33	5.832	.413,372	311
20	400	314	15½	4 8	72.3	8 0	66½	3.64	.51	1.36	41	28.5	1.56	7.200	.520,800	334
22	484	380	15½	4 10	73.71	8 6	75½	3.93	.56	1.6	48	33.6	1.81	8.712	.642,162	355
24	576	452	15	5 0	75.	9 0	84	4.22	.60	1.86	56	39.3	2.08	10.368	.777,600	374
26	676	531	14½	5 2	76.21	9 6	94	4.52	.645	2.16	65	45.3	2.36	12.168	.927,323	393
28	784	615	14½	5 4	77.3	10 0	104	4.82	.69	2.48	74½	52	2.66	14.112	1,091,328	410
30	900	706	14½	5 6	78.36	10 6	115	5.12	.735	2.82	84½	59.1	2.97	16.200	1,269,432	427
32	1024	814	14	5 8	79.8	11 0	126	5.43	.78	3.18	95½	66.8	3.30	18.432	1,462,272	443
34	1156	907	13½	5 10	80.21	11 6	138	5.74	.825	3.56	107	75	3.64	20.808	1,669,010	459
36	1296	1018	13½	6 0	81	12 0	150	6.05	.87	4	120	84	4.00	23.328	1,889,568	472
38	1444	1134	13½	6 2	81.71	12 6	163	6.37	.91	4.46	134	93.4	4.37	25.992	2,123,806	486
40	1600	1256	13	6 4	82.3	13 0	176	6.69	.95	4.95	148½	103.7	4.76	28.800	2,371,200	498
42	1764	1385	12½	6 6	82.88	13 6	190	7.01	.99	5.46	164	114.6	5.16	31.752	2,631,606	510
44	1936	1520	12½	6 8	83.3	14 0	204	7.34	1.03	6.03	181	126.5	5.58	34.848	2,904,000	520
46	2116	1662	12½	6 10	83.71	14 6	219	7.67	1.07	6.63	199	139	6.01	38.088	3,188,346	531
48	2304	1809	12	7 0	84.3	15 0	234	8	1.11	7.26	218	152.5	6.46	41.472	3,483,648	539
50	2500	1963	11½	7 2	84.21	11 0	252	8.33	1.15	7.96	239	166.9	6.92	45.000	3,789,450	548
52	2704	2123	11½	7 4	84.3	11 6	276	8.66	1.19	8.7	261	182.3	7.40	48.672	4,104,672	555
54	2916	2290	11½	7 6	84.36	12 0	300	9	1.225	9.48	284½	198.7	7.89	52.488	4,427,888	561
56	3136	2463	11	7 8	84	12 0	326	9.33	1.26	10.3	310	216.4	8.40	56.448	4,760,448	567
58	3364	2642	10½	7 10	84.21	12 0	354	9.66	1.295	11.22	336½	235.1	8.92	60.552	5,099,084	572
60	3600	2827	10½	8 0	84	12 0	384	10	1.33	12.18	365½	255.3	9.46	64.800	5,443,200	575
62	3844	3019	10½	8 2	83.71	12 0	402	10.33	1.36	13.2	396	276.7	10.01	69.192	5,792,062	579
64	4096	3216	10	8 4	83.3	12 0	426	10.66	1.39	14.3	429	299.8	10.58	73.728	6,144,000	581
66	4356	3421	9½	8 6	82.88	12 0	450	11	1.425	15.46	464	324.3	11.15	78.408	6,498,455	581
68	4624	3631	9½	8 8	82.3	12 0	476	11.33	1.45	16.73	502	350.7	11.76	83.232	6,852,768	583
70	4900	3848	9½	8 10	81.71	12 0	502	11.66	1.475	18.08	542½	378.9	12.37	88.200	7,206,822	583
72	5184	4071	9	9 0	81	12 0	530	12	1.50	19.53	586	409.3	13.00	93.312	7,558,272	581

It may be proper to explain in what way the column in the above Table marked Great Product per Minute was obtained. This was by multiplying together the space described by the loaded piston per minute in feet, its area in circular inches, and again by the pressure per circular inch, estimated in feet of a column of water equal to that pressure. Thus a 26-inch cylinder, whose pressure per circular inch is equal to 18 feet of a column of water of an inch circular base, and whose speed is 76.21 feet per minute, gives for its great product

$$26^2 \times 18 \times 7.62 = 927,323.$$

All the other columns of the Table are sufficiently obvious by the description at their heads.

The experiments above recorded were made about the year 1765, but it was not till 1774 that Smeaton made the first effective improvement from them on an engine at large, when it appeared that he had reduced the expenditure of fuel about one-third. In 1775 he designed the Chase water engine, the cylinder of which was 72 inches in diameter, and the stroke 9 feet. Its power was equivalent to the exertion of 108 horses, and its consumption of fuel was estimated at 1136 pounds of Newcastle coal per hour. At its full power it was proposed to make nine strokes per minute, but to be regulated by the cataraet to four strokes and a half per minute. The construction of the beam and other parts of the engine are sufficiently curious to entitle it to the strict attention of the student of the subject. See Smeaton's *Reports*, vol. ii.

There seemed to be few practical circumstances that escaped Smeaton's inquiry respecting the atmospheric engine; and he drew up for his own use the Table of Proportions, &c. as given above. The Table was not published by the author, but is found in the collection of his papers, purchased by the late Sir Joseph Banks, and now in the possession of the Royal Society. It was first printed in Rees's *Cyclopædia*. But the most important of his researches relate to the load upon the piston; on which he remarks, he had found engines calculated to carry a load varying from under five pounds to upwards of ten pounds to the square inch: those lightly loaded being expected to go with the greatest velocity, so that an engine carrying five pounds to the inch must go with double the velocity of one loaded to ten pounds, the cylinders being of equal area, in order that the effects of the power might be equal. He further adds, in engines, however, as in other Machines, there is a maximum which, without new principles of power, cannot be exceeded. Bad proportions of the parts and bad workmanship may make an engine fall short, in any degree, of what it should do, but its maximum cannot be exceeded by the most accomplished artists. The best speed is now considered to be 220 feet per minute.

(161.) Experiments had, however, in some degree, been directed to a mean burden. The original patentees, (Newcomen and Co.) from some of their first performances, laid it down as a rule to load the piston, so as but little to exceed eight pounds to the inch; but, on more expe-

rience they diminished that load, and amongst the best engines previous to Smeaton's own time, the load was made about seven pounds to the square inch. And he further states, that any proportions will do if the parts be properly proportioned; but, from a long course of very laborious experiments, he had fixed his scale near upon, but somewhat under eight pounds to the inch, including raising the injection water; and this agrees with the load in the best duty engines at this day in Cornwall.

The labours of Smeaton show the imperfect state of Mechanical Science as applied to practice in a remarkable degree, for he designed an engine to be erected at Long Benton to raise water for turning a water wheel to draw coals from a pit; and in 1781 proposed one of Boulton's and Watt's engines to be erected for raising water for driving a corn-mill at Deptford; using such arguments as the following in support of his opinion. "It is to be apprehended," he says, "that no motion communicated from the reciprocating beam of an engine, can ever act with perfect equality and steadiness in producing a circular motion, like the regular efflux of water in turning a water wheel; and much of the good effect of a water-mill is well known to depend upon the motion communicated to the millstones being perfectly equable and smooth; the least tremour or agitation takes off from the complete performance." Secondly, all the engines he had seen were liable to stoppages, and so suddenly, that in making a single stroke the Machine is capable of passing from nearly its full power and motion to rest; for whenever the steam gets lowered in its heat below a certain degree, for want of renewing the fire in due time or otherwise, the engine is then incapable of performing its functions. In the raising of water (a business for which the fire engine seems peculiarly adapted) the stoppage of the engine is of no other ill consequence than the loss of so much time, but in the motion of millstones grinding corn, such stoppages would have a particularly bad effect.

We have now traced the history of the invention of the steam engine from its first rude unscientific form, to that period when it was to undergo a most important change in the hands of Watt, but our last descriptive delineation of it is as it existed in 1712, between which period and that we have now arrived at, 1769, many of the improvements already mentioned, and great accuracy of workmanship, had altogether changed the form and mechanism of it, although without any change in its principle of action. Before, therefore, closing this epoch in the history of this important Machine, it would have been proper to exhibit to the reader the nature and form of the atmospheric or Newcomen's engine, after the practice and experience of more than fifty years; but as the engine in this state is given in our theoretical Treatise on MECHANICS, it will be, perhaps, sufficient to refer the reader to that volume; and we shall simply remark here that the great merit of Newcomen was that he separated, as we have already explained, those parts of the engine in which steam was to act, from those in which the water was to be raised, employing a beam between them, the steam being used merely for displacing the air, and then forming a vacuum by condensation.

(162.) It may be proper to observe, that although we have said but little relative to the original engine of Savery, after having described his latest improvement in it, in 1712, yet it was not left in that state; several persons, notwithstanding the improvements of Newcomen, still preferred the former engine, and even since Watt's

patent, attempts have been made to employ in some cases the principles of Savery: a few lines will not, therefore, be misapplied to point out the peculiarities of these inventions, their authors, dates, &c.

The first we need mention of this class was Blakey, who in 1776 took out a patent for certain improvements in Savery's engine; one of which consisted in employing floating oil upon the surface of the water in the receiver, to form a piston or disc between the steam and cold water: or air was to be admitted into the receiver for the same purpose.

In this case two receivers were to be used, one in the same situation as Savery's, which was to receive the air; and the hot steam, when admitted into it, forced the air to descend by a pipe to a second receiver, which was at the bottom of the well, and expel the water therefrom, and elevate it in the force pipe. By this means he hoped to prevent the steam coming in contact with the water, and thus to avoid the condensation.

Mr. Blakey afterwards made some alterations in the form of his engine, which is described as follows by Mr. Ferguson. (See pl. x. fig. 3.) E is the boiler, set in a furnace so as to be surrounded with flame. F is the gauge cock, to ascertain the depth of the water in the boiler. D the steam pipe, to which is soldered the cock and funnel C, for filling the boiler before the engine is set to work. I is an air vessel, and T T an injection pipe, which passes through across the top of the receiver, and has small holes pierced in it for the cold water to drop through, and fall in a shower in the air vessel I, in order to form a condensation; the end of the injection pipe is carried into the steam pipe D to admit a small quantity of water to run down the pipe D, and supply the boiler. V is a receiver, communicating with the air vessel I by a pipe; in the upper part of it is a colander S, with small holes to disperse the injection water, which falls from the air vessel I equally through the receiver V. O is a valve to admit air, which comes through the cock P into the receiver; and H is an occasional cock, to let out the air and steam when the engine is first set to work. Q is a pipe from the receiver V to the box which contains the valves B and N at the bottom of the forcing pipe A, which conveys the water up to the receiver. M is the suction pipe, to draw the water from the well up to the receiver. G is the fire-place belonging to the furnace, in which the boiler is set, and beneath it is an ash-hole. It is needless to say any thing of the scaffold or well, they being always made in proportion to the size of the Machine, and according to the place in which it is to be erected. All the vessels and pipes of this engine are made of strong copper.

In order to set this engine at work, the receiver and pipe A A must be filled with water, which will be retained by the clack B; then more water must be poured into the funnel C, which is on the steam pipe D; from thence it falls into the boiler E, and rises to the level of the cock F, which must be open; but as soon as the water runs from it, the funnel cock C, as well as the gauge cock F, must be shut, and the air gauge cock H must be opened. The fire is then to be put into the furnace G, and as soon as the water is in ebullition in the boiler it creates steam, which finds its way through the pipe D, and forces the air out of the vessel I into the lower receiver V: the air is also forced out at the cock H, the steam following it with great velocity. In a second or two the cock H must be shut, and instantaneously the injection cock L must be opened, which lets

Machinery.
Savery's engine improved by Blakey.

Pl. x.
Fig. 3.

Manufac-
tures.

cold water run through the end of the pipe T T into the steam pipe D, to replace that which has been evaporated out of the boiler E; and it also rushes out on all sides from the little holes which are in the sides of the pipe T T into the air vessel I, and falls on the colander S. This cold water makes a sudden condensation in the vessels I and V, and forms a vacuum, which causes the atmosphere to press on the water, in which the lower end of the pipe N is immersed, and the water ascends the said pipe with great rapidity, and passes through the clack N, and through the pipe Q into the receiver V, till it rises up to O, where is a floating ball fastened to a handle or lever, which in rising turns the key of the cock P, and opens it. There is a valve at the end of the cock which is inside the receiver V, so that as soon as the cock is opened, the valve O is forced up by the air, which rushes through with great quickness and noise into the vessel I; and when that vessel is full of air, the vacuum is destroyed, and no more noise is heard, which gives the notice to shut immediately the injection cock L; that being done, the steam recovers its force, and makes its way through the steam pipe D into the air vessel I; and as the steam increases, being much lighter than the air, it keeps uppermost, and forces the air on the water which is in the receiver V, which water is forced through the pipe Q, and lifting up the clack at B, goes up the pipe A and empties itself into the receiver at top. When all the water is expelled out of the receiver V, the air follows and ascends with great velocity through the water which is in the pipe A. Two or three seconds after the noise of this is heard, the injection cock L must be opened to let in cold water, and cause the same effect as before. The noise of the air rushing in and out of the receiver, gives proper notice when the manager of this hand engine is to open and shut the injection cock, which is the only thing required to work this Machine, when once it has been put in action, in the manner that has been described before.

This engine was not found to answer any better than Savery's, because the air will not make that complete separation between the steam and the cold water which the inventor expected; and there is a great loss of power in compressing the air sufficiently to make it lift the column of water; and in order to get rid of this air, it must be forced up the pipe, which takes as much power of steam as would be required to force up as much water as the air occupied the place of when in its condensed state. Mr. Blakey's intention in the injection of a small quantity of water into the boiler at every stroke, was the same as Mr. Payne's red-hot boiler, of which we have before spoken; but he was in practice obliged to employ a steam cock in the pipe D, otherwise the steam which the boiler produced while the injection cock was open would have been all condensed and lost.

Savery's engine can be usefully employed for lifting water thirty or thirty-five feet, which can be done principally by suction, and with a very slight pressure for the remainder; but it is the most advantageous way to raise no more than twenty-four feet, and perform the whole lift by the suction, and even to allow the water a sufficient descent to empty the receiver by its own gravity, without forcing it in the least by the steam. In this form of the engine, the steam need have no greater elastic force than the atmospheric air, or just as much as is sufficient to make it enter into the receiver, as the water runs out. The temperature of the steam, according to our Table, will then be only a little above the boiling point,

or above 215° , and, consequently, the loss by the condensation is not so serious; and as the steam is not pressed upon the water, it is not brought into such close contact with the cold water, as in the forcing engines. In this way the injection must be forced in by a small force pump.

(163.) *Pontifax's improvement.*—The most modern application of Savery's principle was that made by Mr. Pontifax, for which he took out a patent in 1819: this is shown in pl. x. fig. 4, 5, in which, fig. 5 is a back elevation, and fig. 4 a side elevation of the engine: *b b*, fig. 5, are two steam cylinders connected by cross tubes at *c c*, in each of which a vacuum is alternately formed by the condensation of elastic vapour, conducted from the boiler by the bent tube *d*, and admitted to the steam cylinders by means of a sliding valve.

f f, fig. 5, are two tubes perforated with small holes for the admission of steam and injection water, the latter of which is distributed by falling on the stirrup *g*. At *h*, fig. 4, is seen the suction pipe proceeding to the bottom of the well, which in no case ought to exceed from twenty-eight to thirty feet in depth; so that a vacuum being formed in the copper vessels *b b*, the water will be raised by the pressure of the atmosphere, and passing up the tube *h*, will take the place of the elastic vapour. Two valves are placed at the upper end of the suction pipe *h*, which allow of the upper passage of the water from the well, but prevent its return; two similar valves open into the air vessel *k*, to which is attached the nozzle *l*, serving to convey the water from the copper vessels to any required point; *m* is the injection tube, furnished with a valve at *o*, and intended to convey water from the box *n* to the taper tubes *f f*. A stop cock is seen at *p*, to regulate the supply of condensing water; *q* is a tube passing from the bottom of the cistern *n* to the injection tube *m*, and furnished with a stop cock at *s*.

The quantity of water in the cistern *n* is regulated by a floating valve *t*, which in fig. 5 is represented immediately over the pipe *q*, so that the valve is opened whenever the water rises beyond the required depth. *u u* are two tubes communicating with the back part of the chambers *n n*, and the inverted vessels *v v*, each tube being furnished with a valve at *w*, to admit the water from the chamber to the buckets *x x*. The two buckets *x x*, which are suspended by rods, and a chain passing over the wheel 2, which is fixed on the end of the axis 3, and supported by a bracket 4. From the other end of the axis projects an arm 6, provided with a stud 7: 9 is a view of the horizontal axis turning in a stuffing box at 10, on one end of which is fixed a pinion, which serves to give motion to the sliding valve.

To put this engine in action, the steam must be first raised to the boiling point, and the valve or cock opened, which admits it to pass from the boiler to the pipe *d*. One of the buckets must now be made to descend, which will open the sliding valve *u*, and admit the steam into the cylinder *b*. The atmospheric air, which will thus be expelled from the cylinder, is allowed to pass through the valve *j* and nozzle *l*. The other bucket must then be depressed, and by its action upon the sliding valve it will open a communication for the injection water through the pipe *q q*, which, passing down the perforated tube *f*, will immediately condense the steam, and form a vacuum in the vessel. The whole pressure of the atmosphere being now removed from the suction pipe *h*, the water will rush up to restore the equilibrium, and the vessel *b* being filled will furnish a supply at the bent tube *l*.

Machinery.

Pl. x.
Fig. 4, 5

Manufac-
tures.

Having examined the action of one half of the apparatus, we may suppose the same effect to be produced on the opposite side. The steam will, in the first instance, be admitted by the pipe *c*, and a communication afterwards opened by means of the sliding valve with the condensing water, which by reducing the steam to its original bulk will form a vacuum, and the water will again ascend as in the first vessel.

The stop cock *y* must now be opened, and the bucket *x* first described made to ascend, which will remove the sliding valve *e* to its original position, and admit the steam to the upper part of the first vessel, which will depress the water, and cause it to flow through the valve *j* and nozzle *l*, while at the same time the water will pass through the tube *u u*, in which the valve *w* is inserted beneath the inverted vessel *v*. The water will continue to enter the bucket *x* till its increasing weight causes it to preponderate, and turn the sliding valve *e* in the opposite direction.

Should there not be a sufficient supply of water in the cistern *n n* for the purpose of condensing the steam in the large vessels, the stop cock *p* must be opened, and an additional supply of water will then be furnished from the chambers *n n* by the tube *m*; and in the event of the bucket not being depressed at the instant that the water is expelled from the chamber *n* of the vessel *b*, the steam will pass through the tube *u u*, and act between the under side of the fixed inverted vessel *v*, and the surface of the water in the movable bucket being accelerated by the repellent force of the steam, so that by the alternate action of the buckets *x x* the motion of the engine is rendered continuous.

It appears that each steam vessel in the engine employed at the City Gas Works contained about thirty-six gallons of water, which is raised about twenty-eight feet three times every two minutes; one bushel of coals, or two of coke, serving the boiler about two hours and three-quarters.

Brown's gas engine is also similar in its principle to Savery's engine, except that the operating agent is gas instead of steam. An engine of this kind is at work at Croydon, in Surrey, and is said to be performing satisfactorily. Several other attempts to improve this early engine have been made by Mr. Keir and others, but we believe it will not be necessary to interrupt the general train of the history of the steam engine by describing them. We now proceed, therefore, to treat of the great changes effected in it by Mr. Watt.

Mr. Watt's Improvements,

IId Period, from 1769 to 1800.

Mr. Watt's
improvements.

(164.) We now arrive at an entire new era in the history of the steam engine. It had not to this time even acquired that denomination, but was generally known as the fire engine; it now for the first time became effectually a steam engine, by the substitution of steam for propelling the piston instead of the atmospheric pressure. While the atmosphere was employed to produce the effective downstroke of the piston, and cold water floating on this piston to preserve it steam tight, it was impossible to preserve the cylinder at a tolerably high temperature; but this was still further rendered impracticable by the means used for producing the condensation. And these were two of the great questions to which Mr. Watt directed his attention, and for which he found the most ample remedies. Another important proposition is con-

tained in his first patent, namely, to work the steam expansively, that is, to cut off the admission of steam to the cylinder sometime before the stroke is completed, which has a very advantageous effect. See Art. 142, of the last Chapter.

The enumeration of these improvements will convey to the reader, not versed in the nature of the steam engine, a very inadequate idea of their importance; it is, however, to them we are in a great measure indebted for the extraordinary pitch to which Machinery and Manufactures have since been carried in this Country; they are therefore entitled to more than ordinary notice.

(165.) It appears that so early as 1761, Mr. Watt had made experiments with a Papin's digester on the power of steam, and that in the winter of 1764 he had his attention again directed to the subject, by being called upon to repair a small working model of a Newcomen's engine belonging to the University of Glasgow. At that time it appears, from his own statement, that what knowledge he possessed on the subject he derived only from Desaguliers and Belidor; and he set about the repairs as a mere mechanic; and when that was done and it was set to work, he was surprised to find that its boiler could not supply it with steam, though apparently quite large enough; (the cylinder of the model being two inches in diameter, with a six-inch stroke, and the boiler about nine inches diameter;) by blowing the fire it was made to make a few strokes, but required an enormous quantity of injection water, though it was very lightly loaded by the column of water on the pump. It soon occurred that this was caused by the little cylinder exposing a greater surface to condense the steam, than the cylinders of large engines did in proportion to their contents; it was found also that by shortening the column of water in the pump, the boiler could supply the cylinder with steam, and that the engine could work regularly with a moderate quantity of injection. It then appeared that the cylinder of the model being of brass, would conduct heat much better than the cast-iron cylinders of larger engines, (generally covered on the inside with a stony crust,) and that considerable advantage could be gained by making the cylinders of some substance that would receive and give out heat slowly. Of these wood seemed to be the most likely, provided it should prove sufficiently durable. A small engine was therefore constructed with a cylinder six inches diameter, and twelve inches stroke, made of wood, soaked in linseed oil, and baked to dryness. With this engine many experiments were made; but it was soon found that the wooden cylinder was not likely to prove durable, and that the steam condensed in filling it still exceeded the proportion of that required for large engines, according to the statements of Desaguliers. It was also found that all attempts to produce a better exhaustion by throwing in more injection water, caused a disproportionate waste of steam.

By experiments which he then tried upon the heats at which water boils under several different pressures greater than that of the atmosphere, it appeared that when the heats proceeded in an arithmetical, the elasticities proceeded in some geometrical ratio; and by laying down a curve from his data, he ascertained the particular one near enough for his purpose. It also appeared, that any approach to a vacuum could only be obtained by throwing in large quantities of injection, which cooled the cylinder so much as to require great quantities of steam to heat it again, out of proportion to the power gained by the more perfect vacuum; and that

His first ex-
periments

Experi-
ments con-
tinued.

Manufac-
tures.

the old engineers had acted wisely in contenting themselves with loading the engine with only six or seven pounds on each square inch of the area of the piston. It being evident that there was a great error in Desaguliers's calculations of Mr. Beighton's experiments on the bulk of steam, a Florence flask, capable of containing about a pound of water, had about one ounce of distilled water put into it, a glass tube was fitted into its mouth, and the joining made tight by lapping that part of the tube with packthread, covered with glazier's putty. When the flask was set upright, the tube reached down near to the surface of the water, and in that position the whole was placed in a tin reflecting oven before a fire, until the water was wholly evaporated, which happened in about an hour, and might have been sooner effected had he not wished the heat not much to exceed that of boiling water. As the air in the flask was heavier than the steam, the latter ascended to the top, and expelled the air through the tube. When all the water was evaporated, the oven and flask were removed from the fire, and a blast of cold air was directed against one side of the flask, to collect the condensed steam in one place. When all was cold, the tube was removed, the flask and its contents were weighed with care, and the flask being made hot, it was dried by blowing into it with bellows, and when weighed again was found to have lost rather more than four grains, estimated at four and a half grains. When the flask was filled with water, it was found to contain about $17\frac{1}{8}$ ounces avoirdupois of that fluid, which gave about 1800 for the expansion of water converted into steam of the heat of boiling water.

This experiment was repeated with nearly the same result; and in order to ascertain whether the flask had been wholly filled with steam, a similar quantity of water was for the third time evaporated; and, while the flask was still cold, it was placed inverted, with its mouth (contracted by the tube) immersed in a vessel of water, which it sucked in as it cooled, until in the temperature of the atmosphere it was filled to within half an ounce measure of water. In repeating this experiment afterwards, Mr. Watt simplified the apparatus by omitting the tube, and placing the flask on its side in the oven, partly closing its mouth by a cork, having a notch on one side, and in other respects proceeding in the manner above mentioned.

These experiments are not stated by Mr. Watt as extremely accurate, the only scale beam he had at the time at his command not being very sensible, and the bulk of the steam being liable to be influenced by the heat to which it was exposed, which in the way described was not easily regulated or ascertained; and from further experiments it appeared that the expansion was more than was thus computed. These experiments were as follows.

Another
series.

(166.) A boiler was constructed which showed, by inspection, the quantity of water evaporated in any given time, and whereby could be ascertained the quantity of steam used in every stroke by the engine, which was found to be several times the capacity of the cylinder. Mr. Watt, astonished at the quantity of water required for the injection, and the great heat it had acquired from the small quantity of water in the form of steam which had been used in filling the cylinder, and thinking he had made some mistake, tried the following experiment. A glass tube was bent at right angles, one end was inserted horizontally into the spout of a tea-kettle, and the other part was immersed perpendicularly in well water contained in a cylindric glass vessel, and steam

was made to pass through it until it ceased to be condensed, and the water in the glass vessel was become nearly boiling hot. The water in the glass vessel was then found to have gained an addition of about one-sixth part from the condensed steam. Consequently, water converted into steam can heat about six times its own weight of well water to 212° , or till it can condense no more steam. Being struck with this remarkable fact, and not understanding the reason of it, Mr. Watt mentioned it to his friend Dr. Black, who then explained to him his doctrine of latent heat, which he had taught for some time before this period. See Art. 125.

On reflecting further, it was perceived, that in order to make the best use of steam it was necessary, first, that the cylinder should be maintained always as hot as the steam which entered it; and, secondly, that when the steam was condensed, the water of which it was composed, and the injection itself, should be cooled down to 100° , or lower, where that was possible. The means of accomplishing these points did not immediately present themselves; but early in 1765 it occurred to Mr. Watt that if a communication were opened between a cylinder containing steam and another vessel which was exhausted of air and other fluids, the steam as an elastic fluid would immediately rush into the empty vessel, and continue so to do until it had established an equilibrium; and if that vessel were kept very cool by injection, or otherwise, more steam would continue to enter until the whole was condensed. But both the vessels being exhausted, or nearly so, how was the injection water, the air which would enter with it, and the condensed steam to be got out? This, says Mr. Watt, I proposed, in my own mind, to perform in two ways. First, by adapting to the second vessel a pipe reaching downwards more than 34 feet, by which the water would descend, (a column of that length overbalancing the atmosphere,) and by extracting the air by means of a pump.

The second method was by employing a pump, or pumps, to extract both the air and the water, which would be applicable in all places, and essential in those cases where there was no well or pit.

(167.) This latter method was the one preferred, and is the only one now ever thought of. In Newcomen's engine the piston is kept tight by water, which could not be applicable in this new method; because if any of it entered into a partially exhausted and hot cylinder, it would boil and prevent the production of a vacuum, and would also cool the cylinder by its evaporation during the descent of the piston; to remedy this defect Mr. Watt employed wax, tallow, or other grease, to lubricate and keep the piston tight. It next occurred to him that the mouth of the cylinder being open, the air which entered to act on the piston would cool the cylinder, and condense some steam on again filling it; he therefore proposed to put an air-tight cover upon the cylinder, with a hole and stuffing box for the piston rod to slide through, and to admit steam above the piston to act upon it instead of the atmosphere. There still remained another source of destruction of the steam, viz. the cooling of the cylinder by the external air, which would produce an internal condensation whenever steam entered it, and which would be repeated every stroke; this was proposed to be remedied by an internal cylinder containing steam, surrounded by another of wood, or of some other substance which would conduct heat slowly.

"When once," says Mr. Watt, "the idea of the separate condensation was started, all these improve-

Machinery.

Best principles of
employing
steam.

Invention of
the detached
conductor.

Packing
the piston.

Manufac-
tures.

These new
ideas sub-
mitted to
experiment

ments followed as corollaries in quick succession, so that in the course of one or two days, the invention was thus far completed in my mind, and I immediately set about an experiment to verify it practically. I took a large brass syringe $1\frac{3}{4}$ inches diameter, and ten inches long, made a cover and bottom to it of tin plate, with a pipe to convey steam to both ends of the cylinder from the boiler; another pipe to convey steam from the upper end to the condenser; and in order to save apparatus, I inverted the cylinder, I drilled a hole longitudinally through the axis of the stem of the piston, and fixed a valve at its lower end, to permit the water which was produced by the condensed steam on first filling the cylinder to issue. The condenser used upon this occasion consisted of two pipes of thin tin plates, ten or twelve inches long, and about one-sixth inch diameter, standing perpendicular and communicating at top with a short horizontal pipe of large diameter, having an aperture on its upper side, which was shut by a valve opening upwards. These pipes were joined at bottom to another perpendicular pipe of about an inch diameter, which served for the air and water pump; and both the condensing pipes and the air pump were placed in a small cistern filled with cold water."

The steam pipe was adjusted to a small boiler. When steam was produced, it was admitted into the cylinder, and soon issued through the perforation of the rod, and at the valve of the condenser. When it was judged that the air was expelled, the steam cock was shut and the air-pump piston rod was drawn up, which leaving the small pipes of the condenser in a state of vacuum, the steam entered it and was condensed. The piston of the cylinder immediately rose and lifted a weight of about 18 pounds, which was hung to the lower end of the piston rod. The exhausting cock was shut, the steam was readmitted into the cylinder, and the operation was repeated, the quantity of steam consumed and the weights it could raise were observed, and, excepting the non-application of the steam case and external covering, the invention was complete in so far as regarded the savings of steam and fuel.

A large model, with an outer cylinder and wooden case, was immediately constructed, and the experiments made with it served to verify the expectations the inventor had formed, and to place the advantage of the invention beyond the reach of doubt. It was found convenient afterwards to change the pipe condenser for an empty vessel, generally of a cylindrical form, into which an injection played, and in consequence of there being more water and air to extract, to enlarge the air pump.

"The change was made, because, in order to procure a surface sufficiently extensive to condense the steam of a large engine, the pipe condenser would require to be very large, and because the bad water with which engines are frequently supplied, would crust over the thin plates, and prevent their conveying the heat sufficiently quick. The cylinders were also placed with their mouths upwards and furnished with a working beam and other apparatus, as was usual in the ancient engines; the inversion of the cylinder, or rather of the piston rod, in the model being only an expedient to try more easily the new invention." The immense importance of this discovery will form an ample apology for the preceding long description and quotation. It is gratifying to enter the workshop and laboratory of such a distinguished practical philosopher, to be made familiar with his thoughts, to see all his difficulties, and witness his in-

genuity in overcoming them; and although we may Machinery. not be able to do so in reality, we may in imagination, while reading the plain unsophisticated statement of this celebrated mechanic, which contains a complete developement of the steps of his improvements, although there was still required the exercise of further ingenuity to put them into the best form for general practice.

(168.) He now, 1769, took out his first patent embody- Mr. Watt's first patent. ing these several inventions expressed in very general and concise terms, entitled For Methods of lessening the Consumption of Steam, and consequently of Fuel, in Fire Engines, as follows: "First that vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire engines, and which I call the steam vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it: first, by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and, thirdly, by suffering neither water nor any other substance colder than the steam, to enter or touch it during that time. Secondly, in engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam vessels or cylinders, although occasionally communicating with them; these vessels I call condensers and, whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water or other cold bodies. Thirdly, whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam vessels or condensers by means of pumps wrought by the engines themselves, or otherwise. Fourthly, I intend in many cases to employ the expansive force (pressure) of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire engines. In cases where cold water cannot be had in plenty, the engines may be wrought by the force of steam only, by discharging the steam into the open air after it has done its office. Fifthly, when motions round an axis are required, I make the steam vessels in form of hollow rings or circular channels, with proper inlets and outlets for the steam, mounted on horizontal axles like the wheels of a water-mill; within them are placed a number of valves that suffer any body to go round the channel in one direction only; in these steam vessels are placed weights so fitted to them, as entirely to fill up a part or portion of their channels, yet rendered capable of moving freely in them by the means hereinafter mentioned or specified. When the steam is admitted in these engines between these weights and the valves, it acts equally on both, so as to raise the weight to one side of the wheel, and by the reaction on the valves successively, to give a circular motion to the wheel, the valves opening in the direction in which the weights are pressed, but not in the contrary: as the steam vessel moves round it is supplied with steam from the boiler, and that which has performed its office may either be discharged by means of condensers, or into the open air. Sixthly, I intend in some cases to apply a degree of cold not capable of reducing the steam to water, but of contracting it considerably, so that the engines shall be worked by the alternate expansion and contraction of the steam. Lastly, instead of using water to render the piston or

Manufac-
tures.

other parts of the engines air and steam tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals in their fluid state.

"Be it remembered, that the said James Watt doth not intend that any thing in the fourth article shall be understood to extend to any engine where the water to be raised enters the steam vessel itself, or any vessel having an open communication with it."

This specification, as has been before observed, is very comprehensive; it embraces the grand idea of condensing in a separate vessel called the condenser to be kept always cold, of working the engine by steam, thereby keeping the cylinder always hot. It proposes to work by the expansive power of steam; but it is perhaps doubtful whether this means what is now called working expansively, as this was embraced in a subsequent patent; the high pressure engine is also included, although, as we have seen, (Art. 155.) this had been before proposed by Leupold. Other principles of working rotatively, &c. are included, but as these never have been made to succeed well, any further notice of them is unnecessary.

Conversion
of the reci-
procating
into a circu-
lar motion
to drive
Machinery.

(169.) The rotary principle not succeeding, Mr. Watt's next idea seems to have been to convert the rectilinear and reciprocating motion of the piston into a rotary motion. This had been before attempted by Halls, as we have already described, (Art. 156.) by Fitzgerald, and by Steward, in the year of the above patent, 1769, and subsequently by Steed in 1781; for the simple crank now universally adopted, and which, considering the very common use of this method in the turning lathe, and even in the razor-grinder's wheel, seems most unaccountably to have been overlooked by Mr. Watt. It is indeed said that he had been making experiments on the use of the crank; that these experiments were made known to Mr. Steed, who immediately took out his patent, and thereby prevented Watt from so doing. This patent, however, was not granted till 1781, twelve years after the above patent, the loss of which time appears certainly rather unaccountable. At all events, in 1781, Watt obtained a second patent, in which great ingenuity is exercised in obtaining a rotary motion without interfering with other patents for this purpose; and, although five distinct methods are proposed, amongst which is the sun and planet wheel, not one of them is so simple and advantageous as the simple crank of Steed. And it would certainly have been a more gratifying task to the historian to have had in this place to say, that Mr. Watt had adopted this method by giving a due compensation to the patentee, than to record the efforts of his genius, exercised merely for the purpose of excluding an ingenious rival from participating in the glory and advantages of his construction. If it be true, indeed, that Steed obtained his patent clandestinely, this may afford some apology; but the interval, as we have said above, was very considerable between 1769, the date of Watt's first patent, and that of Steed's in 1781. However this may be, Mr. Watt's second patent, taken out the same year as Steed's, embraced five different methods of producing rotation, of which the sun and planet wheel was one, and was employed by him for several years, till the crank patent expired.

Hornblow-
er's patent.

(170.) In this same year 1781, a patent was obtained by a very ingenious mechanic, Jonathan Hornblower, of Penryn, Cornwall, for a mode of applying expanding steam, by employing two cylinders, by the use of which the force of the apparatus is more nearly equalized.

This has been the basis of several improvements of the first importance in the introduction of double cylinder engines. The following specification is given in the author's own words.

"First I use two vessels in which the steam is to act, and which in other steam engines are called cylinders. Secondly, I employ steam after it has acted in the first vessel to operate a second time in the other, by permitting it to expand itself, which I do by connecting the vessels together, and forming proper channels and apertures, whereby the steam shall occasionally go in and out of the said vessels. Thirdly, I condense the steam, by causing it to pass in contact with metallic substances, while water is applied to the opposite side. Fourthly, to discharge the engine of the water employed to condense the steam, I suspend a column of water in a tube or vessel constructed for that purpose, on the principles of the barometer, the upper end having open communication with the steam vessels, and the lower end being immersed in a vessel of water. Fifthly, to discharge the air which enters the steam vessels with the condensing water or otherwise, I introduce it into a separate vessel, whence it is protruded by the admission of steam. Sixthly, that the condensed vapour shall not remain in the steam vessel in which the steam is condensed, I collect it into another vessel, which has open communication with the steam vessels, and the water in the mine, reservoir, or river. Lastly, in cases where the atmosphere is to be employed to act on the piston, I use a piston so constructed as to admit steam round its periphery, and in contact with the sides of the steam vessel, thereby to prevent the external air from passing in between the piston and the sides of the steam vessel."

This method of working possesses many advantages, but, unfortunately for the inventor, he could not avail himself of them, because the improved mode of condensation which was essential to its operation remained the right of Boulton and Watt.

(171.) While we are speaking of this ingenious idea of Hornblower, it will be well also perhaps to record some further efforts of his genius, although they were of some years later date than that we are at present arrived at. These relate to two different methods for which he obtained patents for producing a rotary engine, or one which should communicate rotation from its first action. His first was a very ingenious but complicated Machine the patent for which is dated 1798. The second was more simple; it was secured by a patent in 1805. It consists of four vanes revolving in a cylinder round its axis. The vanes are like those of a smoke-jack, but of thickness sufficient to form a groove in their edges, to hold stuffing for the purpose of making them steam tight in their action. They are mounted on an arbour which has a hollow nave in the middle. Into this nave the tails of the vanes are inserted, and each opposite vane affected alike by making a firm connection with one another; so that if the angle of one of the vanes with the arbour be altered, the opposite one will be altered also, and the opposite ones are set at right angles to each other; wherefore when a vane is flatly opposed to the steam, the opposite vane will present its edge to it, and this they are constantly doing in their rotation on their common arbour. Hence the steam acts against the vane on its face for about a quarter of a circle, or ninety degrees, in the cylinder where it is destined to act; and as soon as it has gone through the quarter of the circle, it constantly turns its edge to the steam, while at the same

Machinery.

Hornblow-
er's rotary
engine.

Manufac-
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instant another vane has entered the working part of the revolution, and the rotation proceeds without interruption. This engine was to be furnished with the condenser and discharging pump of Watt, but Hornblower added what he considered an improved method of discharging the air from the condenser.

It is easy to show that the friction, and other sources of loss of power, are much greater in the rotary than in the rectilinear action of the steam, while the loss by rendering a reciprocating motion rotary is very small; but this is noticed as one of the most simple combinations proposed for a rotary engine.

Mr. Watt's
patent,
1782, for
double act-
ing engine,
and for
working ex-
pansively.

(172.) It has been thought convenient to collect into one series the three distinct patents of Mr. Hornblower, although it was necessary in order to do so to anticipate by some years the thread of our history. We must, however, now retrace our steps, commencing with an account of Mr. Watt's patent, registered in 1782, embracing various methods of applying steam. First for an expansive engine with six different contrivances for equalizing the power. Secondly, the double pressure or double power engine, in which the steam is alternately made to press on each side of the piston, while a vacuum is formed on the other. Thirdly, a new compound engine, or method of connecting together the cylinders and condensers of two or more distinct engines, so as to make the steam which has been employed to press on the piston of the first, act expansively upon the piston of the second, &c., and thus derive an additional power to act either alternately or conjointly with that of the first cylinder. Fourthly, the application of toothed racks and sectors to the end of the piston or pump rods, and to the arches of the working beams, instead of chains. Fifthly, a new reciprocating, semirotative engine, and a new rotative engine or steam wheel.

Working
expan-
sively.

Of these six divisions of the patent, the two which refer to working by expansion and the double action on the piston are by far the most important. It has been observed that the expression "of working by the expansive power of steam" occurs in the first patent; but it was not put in practice till 1778. In this patent this is proposed to be done in three different ways: first by gradually opening the regulating valves, which admit the steam to act on the piston, and letting it continue so to open during the whole length of the stroke; secondly, by letting them open fully at first, and shutting them completely when the piston has proceeded only part of its stroke; or, thirdly, by the use of a throttle valve placed in the pipe, which, acting in the same manner as the floodgate of a mill, admits no more steam than gives the desired power. The second of these methods is decidedly the best, and, as above stated, consists in shutting off the further entrance of steam from the boiler, when the piston has been pressed down in the cylinder for a certain proportion of its total descent, and then leaving the remaining part of the stroke to be accomplished by the expansive force of that steam which has been already introduced into the cylinder. This gives the means of regulating the acting force of the engine; because the pin of the frame, called the plug frame, which opens and shuts these valves, can be placed in such a manner, that the steam valve shall be shut when the piston has descended one-half, one-third, one-fourth, or any other proportion or part of the stroke; and so far the cylinder will be occupied with steam of the same elasticity as that in the boiler, which is usually a little in excess of that of the atmosphere. In order to press the

piston further down, the steam must expand; and though its elasticity is thus diminished, it will be enough to complete the stroke. It is plain that this can be done in any degree at pleasure, as the adjustment of the pins in what is called the plug frame can be varied in an instant; and, according as the engine requires more or less power, allow the steam to act with its full force upon the piston for a greater or less portion of its total descent. If this method of working an engine had no other advantage than the regulation of the power, it would not effect the end better than the throttle valve; but by the expansive principle a great saving of steam is made. It has been observed of Newcomen's engine, that the motion of the piston is accelerated in its descent by the continued action of the pressure of the atmosphere while the load is constant, or even greater at first. Mr. Watt's engine is the same, but in a less degree, when it has a throttle valve, because the steam cannot then come to the piston, except in a limited quantity; but when the top of the cylinder is open to the boiler, or the throttle valve fully open, the effect is the same as if the atmospheric air had free entrance into the top of the cylinder. Now by stopping the further entrance of the steam at a certain portion of the stroke, the piston can be made to descend with an uniform velocity, by the expenditure of only a portion of that quantity of steam which would be required, if steam of its full density were employed to press it down to the bottom with an accelerated velocity.

Machinery

But when the steam is shut off at a portion of the stroke, the pressure on the piston is continually diminished as the steam becomes more and more rare; and, consequently, the motive force which works the engine diminishes. The motion of the piston, therefore, will no longer be uniformly accelerated, but will approach towards uniformity, or it may even be retarded; because, although the pressure on the piston at the beginning of the stroke may exceed the resistance of the load, yet when the piston is near the bottom, the diminution of the pressure may occasion the resistance to exceed the pressure; in this case the motion can only be continued by the momentum of the moving parts. Whatever may be the law by which the pressure on the piston varies, it is possible to contrive the connecting Machinery in such a way, that the chains or rods at the outer end of the beam shall continually exert the same pressure to lift the pump rods, or that the Machinery shall vary its force according to any law which is found most convenient. This may be done on the same principle that the watchmaker, by the form of the fusee, transmits an equal pressure to the wheel-work, from a very unequal action of the main spring. In like manner, by making the communication from the piston rod to the pump rod by means of chains, which wind upon arch heads, formed to portions of a proper spiral instead of a circle, the force of the piston upon the beam and pump rods can be regulated at pleasure, so as to produce an uniform effect.

(173.) In the preceding Chapter on steam, (Art. 142.) we have given Mr. Davies Gilbert's investigation of the effect of expansive working, and have shown, that if that part of the stroke during which the steam continues its full action be denoted by 1, and the remaining part of the stroke by n , the efficiency of the power on the whole stroke will be $\text{hyp. log. } (1 + n)$; the efficiency, therefore, increases as n increases, and is infinite when n is infinite. It must be observed, however, that in this reckoning an

Manufac-
tures.

The double
acting prin-
ciple.

important element, time, is omitted, and although, according to the method of estimating the efficiency of an engine in Cornwall, the consumption of fuel is the only criterion, yet in general practice time is important, as is also the length of the stroke, which cannot conveniently exceed a certain quantity. We cannot, therefore, attempt to settle such questions by the fluxional or differential calculus. It is sufficient to say, that long practice has proved the value of this part of Mr. Watt's patent, and that it is universally adopted.

(174.) Of the double acting principle, up to this time every engine, whether atmospheric, or a steam engine properly so called, because the piston is propelled by steam, were only what is now called single acting engines; that is, the piston, after having completed the working or down stroke, returned inefficient to the top to be again depressed; but, by this new contrivance, the same cylinder was rendered capable of doing double the quantity of work in the same time, the steam pressure acting and the condensation taking place both during the ascent and descent of the piston. This change was very simple, but very advantageous. It renders the power nearly uniform, diminishes the proportion of cooling surface, a less boiler is necessary, and it reduces the bulk and weight of the engine, the power remaining the same. Another step was still wanting to complete the mechanism of the double acting engine, namely, a guide for the piston rod; and this appears to have been first accomplished in 1784, by the invention of what is called the parallel motion. This is an ingenious combination of levers, (explained in a subsequent article,) one point of one of the levers describing nearly a straight line, to which point the piston rod is connected, so that its rectilinear motion causes the beam to vibrate. This Mr. Watt secured by patent in 1784, and at the same time the following other inventions; viz. first, a new rotative engine, in which the steam vessel was to turn upon a pivot, and be placed in a dense fluid, the resistance of which to the action of the steam was to cause the rotary motion. Second; an improved method of applying the steam engine to the working of pumps or other alternating Machinery, by making the rods balance each other. Third; a new method of applying the power of steam engines to move mills, which require to have many wheels moving round in concert. Fourth; a simplified method of applying the power of steam engines to working of heavy hammers or stampers. Fifth; a new construction and mode of opening the valves. Sixth; an improved working gear; and seventh, a portable steam engine and Machinery for moving wheel carriages.

Another patent was obtained by Mr. Watt in 1785, for a method of constructing furnaces, in which the best principles philosophy could furnish, are applied to elicit the heat, and consume the smoke of the fuel. He also applied to the steam engine the conical pendulum or governor, (Art. 69.) the steam gauge, the condenser gauge, and a useful little instrument for ascertaining the state of the steam in the cylinder, called an indicator.

We have now run through an account of all Mr. Watt's ingenious contrivances, but only barely noted those, by far the greater number, which have found no application either in his own hands nor in those of others; the rest are of the highest importance, and are accordingly stated in greater, and it is hoped in sufficient, detail. It remains now to exhibit his engine, and to explain many of the particulars above verbally stated, by diagrams, indeed, they cannot be properly understood without them,

and which will complete what may properly be considered a second epoch in the history of this noble Machine.

(175.) Mr. Tredgold, in concluding the short account he has given of Mr. Watt's inventions, passes him in review as an author, observing, that "the only part of the theory of the action of steam which Mr. Watt attempted to investigate from first principles is the power it affords by expansion, and this is done imperfectly. The proportions and mode of construction he adopted, seem to have been obtained wholly from trial, and the natural consequence was, a long delay before he brought his engine into use; for though his facility of invention must have been considerable, his means of judging of the value of his combinations were very limited; indeed, he appears to have possessed no other certain test than the expensive and slow mode of proving each by making models and trial Machines. On the ground of not having been remunerated for these expensive trials, he got the term of his patent extended to 1800; and, in consequence, with his partners, made a rapid fortune. He devoted a considerable portion of the latter part of his life to Chemical Philosophy, and particularly its application to the Arts. As an author, he has contributed on the steam engine only some historical notices of his own inventions, a few corrections of Dr. Robison's article in his *Mechanical Philosophy*, and notes to it containing his experiments on the latent heat and elastic force of steam, not given in detail to the world till they were rendered unnecessary by the inquiries of others."

The share which Boulton had in the improvement and introduction of the steam engine must not be forgotten; for, as it has been remarked by Baron Dupin, "Watt's engine was, when invented by him, but an ingenious speculation, when Boulton, with as much courage as foresight, dedicated his whole fortune to its success." He did not hesitate even when Smeaton declared his conviction that it could never be generally applied as a useful agent. Besides, Boulton rendered no small service to Watt and to Great Britain when, by his extraordinary talents in Manufactures and Commerce, he exempted his partner from all the cares of life, from all commercial speculations, and from all those difficulties which are the inevitable consequences of great enterprise in trade. Boulton did still more; he triumphed over all those interests and prejudices which necessarily arose in the beginning to retard the success of the new steam engines and their application." "Men," continues Dupin, "who devote themselves entirely to the improvement of industry, will feel in all their force the services that Boulton has rendered to the Arts and Mechanical Sciences, by freeing the genius of Watt from a crowd of extraneous difficulties which would have consumed those days that were far better dedicated to the improvement of the useful Arts."

In paying this compliment to the well-directed spirit of enterprise on the part of Mr. Boulton, we ought not to pass over in silence the equally meritorious, although less successful scientific adventurer, Dr. Roebuck, who was Mr. Watt's first associate. It was this gentleman who established the iron works at Carron; and he and Mr. Watt proposed establishing an extensive manufactory for steam engines, under Mr. Watt's first patent; and, in fact, the first real engine having a cylinder of eighteen inches diameter was begun by them at Kinneil, near Burrowstowness, at which latter place Dr. Roebuck had immense coal and salt works, which

Machinery.

Manufactures.

not proving successful, he parted with his interest in Mr. Watt's patent to Mr. Boulton. He was, however, amongst the first to appreciate the value of the invention, and supplied the funds requisite for the first attempts.

The preceding notices may be said to complete the history of the steam engine to about the year 1800, since which time no new principle of action has been introduced; although not only have many important improvements been made in the working parts, retaining the engine nearly in the form it had been brought to by Watt, but some considerable changes in its mode of action also have been made by other ingenious men, one or two of which it will be well to describe in this place before we undertake to illustrate the modern engine: but as these are not very commonly adopted, we must content ourselves with a simple verbal description, notwithstanding their ingenuity would fully entitle them to graphic illustration, if our limits would admit of it.

Cartwright's engine.

(176.) *Cartwright's engine* is the first that claims our attention, not only in point of date, being projected in 1797, but also as regards simplicity; it likewise possessed the novelty of being worked by a metal piston, and of returning the whole of the fluid of condensation to the boiler; this fluid having been at first designed to be spirit of wine. The condensation was effected by passing the steam between two large iron cylinders, the inner one being open at its ends, whereby the whole surface of the two cylinders was exposed to cold water: the space between the two being of course closed, except having two valves, one for the admission of the steam and the other for the eduction of the condensed fluid which was drawn from it by a pump, and returned to the boiler. The cylinder, with its piston, was placed over the condensing cistern. The engine was single acting, receiving its steam at the top, and was at bottom open to the cylindric condenser. When the piston arrived at the bottom of its stroke, a passage was opened by a valve in the piston, which placed it in equilibrio in respect of pressure; it now returned to the top of the cylinder, the induction and eduction valves were again opened, and the stroke repeated.

The method adopted for giving the rotary motion was also extremely simple: the piston rod having been made to act on a double crank placed immediately above it, whence rotation was produced by precisely the converse action of the motion described in Art. 77. See also pl. iv. fig. 9.

Woolf's engine.

(177.) *Woolf's engine*.—The mode of condensation invented by Watt being now (1804) become, by the expiration of his patent in 1800, public property, and Hornblower's patent having also ceased, Mr Woolf adopted the arrangement of the latter, with the alteration of using high pressure steam in the small cylinder, and employing the condensing apparatus of Watt. But a change of the working force of steam would have been too slight a ground to have claimed a patent upon, and therefore he commences the specification by a claim to the discovery of a new law of the expansibility of steam. This law of expansibility he stated with great confidence as the result of experiments, in which, however, he had no doubt deceived himself. This assumed law is, that steam generated at any number of pounds per inch above the atmospheric pressure, will expand to an equal number of times its volume, and will be then equal in elastic force to the atmosphere, the temperature being unaltered. Hence steam generated at forty pounds on the square inch above the atmosphere, was expected to ex-

VCL. VII.

pand to forty times its bulk, and still be equal to the atmospheric pressure. Machinery.

This is clearly erroneous; for if even the latent heat of steam were the same at all densities and temperatures, it is obvious that the elastic force of steam at forty pounds above the pressure of the atmosphere is, reckoning that pressure at fourteen pounds, equal in all to fifty-four pounds, and consequently the elastic force after expanding forty times will be but 1.35 pounds per inch instead of 14; and even with an expansion of four times instead of forty, its force would be scarcely equal to the amount stated.

It must be admitted, however, although the inventor was mistaken in this estimate, that, as we have seen in the Chapter on steam, the elasticity of this vapour increases in a much higher ratio than the temperature; and if, therefore, equal degrees of heat could be obtained with equal quantities of fuel, that is, for example, if steam at 220° in contact with water could be raised to 230° with the same consumption of fuel as would raise steam from 210° to 220°, and again that its expansion followed the law last stated, there would still be a great saving by employing Woolf's engine; and even notwithstanding this may, and certainly does, not obtain to its full proportion, yet it may in part, and indeed the engine is generally said to possess some advantages.

To attempt any account of the numerous patents and propositions for real or supposed improvements in the steam engine from the year 1800 to the present time would require a volume of itself. The immense national importance of this engine, its application to navigation, to rail roads, and common road locomotive carriages, &c. seemed to offer favourable opportunities to speculators to secure to themselves the advantages of some real or supposed saving, or to obtain the monopoly of some particular construction; and accordingly for several years our patent lists were crowded with specifications of this kind, many of them certainly containing great improvements, but others serving little other purpose than that of putting fees into the pockets of the several parties attached to the patent offices.

(178.) The following List of Works, either wholly descriptive of the steam engine, or those in which it forms a part only of their contents, will furnish the reader with ready means of reference. List of writers on the steam engine.

Brancas, *Le Machine*, folio, Rome, 1629.

Marquis of Worcester, *Century of Inventions*, 12mo. London, 1663, 1746; Glasgow, 1767; London, 1786, 1813, 1825.

Papin, *Recueil de Pièces*, 8vo. Cassel, 1695.

Savery, *The Miner's Friend*, 8vo. London, 1702.

Isaac de Caus, *New Invention of Water Work*, London, 1704.

Ars Nova ad Aquam Ignis adminiculo efficacissimè elevandam, Cassel, 1707.

John Allen, *Narrative of several New Inventions and Experiments, particularly the navigating a Ship in a Calm, and Improvements on the Engine to raise Water by Fire*, 8vo. London, 1730.

Voyage de la Motraye en Europe, Asie, et Afrique, folio, 3 vol. (see vol. iii. p. 360.) La Haye, 1732.

Hull, *Description of a New Invented Machine for carrying Vessels or Ships out of or into any Harbour, Port, or River, against Wind and Tide*, 12mo. London, 1737.

Desaguliers, *Course of Experimental Philosophy*, 4to. London, 1763.

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Blakey, *Sur les Pompes à Feu*, 4to. Amsterdam, 1774.
 Falck, *Description of an Improved Steam Engine*, 8vo. London, 1776.

Leupold, *Theatrum Machinarum Generale*, folio, Lips. 1780.

Belidor, *Architecture Hydraulique*, 4to. Paris, 1782, 1790.

Bossut, *Traité Théorique et Expérimental d'Hydrodynamique*, 8vo. 2 vol. Paris, 1786, 1787.

Senphin de Mon Copi, *Œuvres de*, 1787.

Prony, *Nouvelle Architecture Hydraulique*, 4to. Paris, 1790, 1796.

Boulton and Watt, *Directions for erecting their New Invented Steam Engine*, 8vo.

Short Statement of Boulton and Watt in opposition to Hornblower's Renewal of Patent, 8vo. London, 1792.

Blakey, *A short Historical Account of the Invention, Theory, and Practice of Fire Machinery; or Introduction to the Art of making Machines, vulgarly called Steam Engines*, 8vo. London, 1793.

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Description of the Modern Steam Engine and Improvements. Machinery

(179.) We have brought up the history of the invention of the steam engine to the termination of Watt's extended patent, from which time we may almost date a new epoch in its progress of improvement; for since that time there has been nearly a total change in the manner of constructing, arranging, and putting together the several parts of the engine, and many advantageous alterations have been made as far as respects the durability and accurate performance of the Machine; although little has been added in point of principle, if we except the second cylinder of Hornblower and Woolf, which has been concisely described in a preceding page, although, for the sake of connection, misplaced in point of date. The high pressure engine likewise, although included in Watt's patent, was not reduced to a proper working form till some years after its expiration; this still remains to be described in a subsequent section.

It would certainly be interesting, if the nature of this Work admitted of it, to show by a series of plates the successive steps which have been made in the progress of this engine from the earliest of Watt's construction to the present time; we should then have to exhibit the large heavy wooden beam with arched heads and chains; or the piston rod with ratchet teeth, and corresponding teeth in the arch head, the sun and planet wheel for producing rotation, and other constructions now wholly laid aside.

This extension of our Essay, however, is inadmissible; and we must, therefore, proceed to describe the modern engine, in which all the principles of Watt have been retained, but the arrangements, proportion of parts, and working gear largely improved by the experience, ingenuity, and better workmanship of later masters. Even of these changes we can attempt the description of only a few of the best, for the variations are nearly as numerous as the engines themselves. We have mentioned Watt's patent for a parallel motion; we have now parallel motions of every variety. Watt placed his cylinders vertically; we have had them since placed horizontally, inclined, and inverted. Watt made his pistons steam tight by packing with hemp; we have had since spring pistons, revolving pistons, metal expanding pistons, &c. The cylinders, besides the particular positions in which different inventors have placed them, have gone through every variety of proportion, a like variety has been tried in the relative proportions of the condenser and air pump, as compared with the cylinders; and the forms of the valves, and the methods of opening and closing them for the admission or eduction of steam to and from the cylinder, &c., have gone through perhaps a greater change than any of the other parts alluded to. But of all the changes which have taken place that of improved workmanship is the most important, which is now very superior to what it was some years back; and to this, perhaps, more than to the change in the actual arrangements, is to be attributed the increased and still increasing power of the steam engine. Hence in the illustrations which are about to be given, the reader should consider only the principle of the engine to be due to Watt, the working parts must be looked upon as resulting from the accumulated ingenuity of all, or of many, of the most distinguished engineers whom England have produced during the last forty years, Watt himself

Introductory remarks to the description of the modern engine.

Changes in the working

Manufactures.

being of the number; many improvements being due to him since the expiration of his patent.

Description of the several Parts of the Modern Steam Engine.

(180.) In order to render the description of the steam engine in its present improved form more intelligible to the general reader, we propose, first, to describe separately the different parts of it which are essential to fully understanding its action, although it will not of course be expected that we can enter into a minute detail on some minor points. A few of the working parts, however, require particular illustration: such as the contrivance for producing a parallel motion, the nature and action of the steam valves, the steam pipes, pistons, cylinders, &c.; these will be found described in the following articles.

Description of the boiler.

(181.) *Of the boiler.*—The boiler, as well from the nature of its duty as from the several self-adjusting apparatus attached to it, calls first for our attention. It will be seen in a subsequent section, indeed it has been shown in Art. 66, that by means of the fly wheel and governor, the speed of the engine may be rendered uniform under various degrees of resistance; but it follows, of course, that when the speed is thus uniform, and the resistance greatly diminished, if the same quantity of steam continued to be generated, it would, for want of the usual demand, increase in density and elasticity, and, without some provision to meet such a case, burst the boiler. This renders it necessary to provide a *safety valve*, which is a common appendage to all boilers. This safety valve allows the overplus quantity of steam to escape; but here again is another evil, unless provided against, *i. e.* the unnecessary destruction of fuel and waste of power. For the prevention of this, the *self-acting damper* has been invented: this, by the means hereafter explained, is so adjusted that when the action of the steam is too great, the damper descends and checks the power of the furnace, and when too small, the damper, by rising, increases its draught and intensity of action. To some boilers are also attached self-adjusting feeders to supply the fuel to the furnace, in which case the feeder is also regulated by the same apparatus which acts on the damper. To some also are attached internal safety valves, to guard the boiler from the effect of external pressure in case of any sudden or unusual condensation of the steam in the boiler.

The *feed pipe* is another attachment likewise self-acting. The demand for steam, as we have seen, is uncertain; the supply of water required, therefore, is also uncertain, and if thrown in by any constant force or pressure would, in some cases, overcharge the boiler with water, and in others allow it to fall so low as to expose the sides and flues to the action of the fire without a proper conducting body to take off the heat, and thereby not only burn and destroy the metal, but lay the foundation for the most serious accidents. Boilers again are supplied with *gauge cocks* with pipes descending into them, to such depths that one of them opens just above the proper surface level of the water, and the other just below it, so that when the water is in proper quantity and the first of these cocks is turned it will yield steam, and the other being turned it will yield water; but if the water is too high in the boiler both pipes will be immersed in, and will give out water, and if too low they will both give steam; the engineer, therefore, by this means, has it always in his power to ascertain the state of his boiler, and whether or not the self-acting feeder is

properly performing its duty. Another attachment to the boiler, or to some pipe in its immediate vicinity, and in connection with it, is the *barometer gauge*, by means of which the elastic power of the steam may be seen at any moment by inspection. These several parts require some explanation, which is given in a subsequent page. At present we shall offer a few rules and remarks relatively to the proper size and figure of the boiler, and the proportional part of its whole capacity which ought to be appropriated to the water and steam.

(182.) *Dimensions of low pressure boilers.*—The pressure per square inch on the piston of course varies in different engines, yet there is a sort of medium pressure generally aimed at, which may be taken at about eight or ten pounds per square inch, after all deductions for friction, air pump, &c.; and as the motion of the piston is also generally about 220 feet per minute, we have 33,000 pounds (the horse power) divided by 220, equal to 150 pounds, or to fifteen inches on the piston for every horse power, when the pressure is ten pounds.

Machinery

Dimensions of low pressure boilers.

$$\text{Hence } \frac{15}{144} \times 10 \times 220 \times 60 = 1375 \text{ cubic feet of}$$

steam employed for every horse power per hour; if to this we add a certain loss of steam at the several valves, &c., and considering 10 pounds per inch as rather on the maximum side, it may be assumed that every horse power requires about one cubic foot of water per minute; for we have seen that where extreme nicety of experiment has been had recourse to, a cubic foot of water will form only about 1711 cubic feet of steam. The assumption, therefore, of one cubic foot of water per hour for each horse is sufficiently accurate for our purpose.

Now the boiler must obviously contain as much steam as will supply the engine at each stroke, with but inconsiderable decrease in its elastic force, and the space will therefore depend on the manner the steam is supplied. If it be admitted to the engine only a part of the time of the piston's descent, there must be so much steam that the use of the quantity required may not lessen its elastic force. If the steam be generated equally, and the space for it only equal to the quantity consumed at each stroke, and all the quantity be wanted during the stroke of the piston, the elastic force in the boiler would vary one half, and the loss of effect would be very considerable. This practice is of course inadmissible in low pressure engines, and generally from five to eight times the quantity used at each stroke should be already existing in the boiler. Dr. Young in one place, without specifying any particular case, says that ten times the volume is sometimes provided. Another practical rule has been given which, however, like the former, seems very uncertain, this is, that every horse power requires 25 cubic feet space in the boiler; others say 20, and, in some instances, it has been stated that as little as 8 cubic feet per horse power have been found sufficient. In land engines, however, the boiler is generally rather larger than real practice requires, so that few fixed and determinate dimensions can be given. The boiler of a 10-horse power engine in His Majesty's Dock-yard at Woolwich is 9 feet long, 4 feet 10 inches deep, and 4 feet 3 inches broad, of which depth 3 feet 9 inches is intended to be occupied by water. The top of the boiler is semi-cylindrical, and the bottom is also partly cylindrical or concave, both concavities being downwards. Another boiler, called a 30-horse boiler, intended to supply two

Manufac-
tures.

14-horse engines, of a similar form, but with a central flue, has its dimensions as follows: length 15 feet, breadth 5 feet 6 inches, and depth 7 feet 6 inches, depth of water 4 feet 9 inches.

In the former the cubic content is about 200 feet, which is 20 feet per horse, and the steam space rather less than a third of the whole, viz. about 60 feet. The capacity of the cylinder or cubic feet of steam used at each stroke 6.8 feet; the steam space, therefore, in this case is between eight and nine times the quantity demanded at each stroke.

In the second boiler, after deducting the flue, the capacity is 465 cubic feet, or $15\frac{1}{2}$ times the horse power, and the steam space about $4\frac{1}{2}$ times the demand for each stroke.

These are two practical examples, but many others might have been given, which would have brought out different proportions. In general, however, some tolerable approximation to what is above stated may be considered as the usual practice.

(183.) The boiler above described has, as we have seen, a semi-cylindrical top, and concave bottom and flue, in other cases the bottom and sides are plane, and very commonly the whole boiler is cylindrical with spherical ends. It does not appear, however, that the form of the boiler is of great importance, but it is very essential, whatever be the form, that a certain proportion of the whole be exposed to the action of the fire. Smeaton was the first who experimented on this subject; and he, from the results of his experiments, constructed a table showing the boiler surface required to be exposed to the effect of the fire and smoke of the fire for atmospheric engines, and the quantity of coals to be consumed per hour. His quantity of surface for one bushel per hour is 88 feet, and for 13 bushels per hour not quite 82 feet of surface per bushel. This is equivalent to 8.2 feet of surface for converting one cubic foot of water into steam at about 220° ; a result which is also verified by Mr. Watt, who says, that with the most judiciously constructed furnaces it requires 80 feet of surface of the boiler to be exposed to the action of the fire and flame to boil off a cubic foot of water per hour. In neither of these cases is there any distinction made between the quantity of surface exposed to the direct action of the fire, that is, to the area of the bottom, and that only exposed to the flame and smoke; but recent observers consider that much depends upon this proportion. In general, however, it may be stated that in common practice from 3 to 5 feet of boiler are appropriated for each cubic foot of water boiled off per hour; but Tredgold states $4\frac{1}{2}$ feet as the proper quantity to be thus appropriated. In the boiler we have described the bottom area scarcely exceeds 3 feet the horse power, and they have always been found to be perfectly efficient.

Some boilers, as we have seen, have central flues, others have only side flues; the one shown in the plate xi. has no central flue, and the progress of the flame and rarefied air is sufficiently obvious. When there is a central flue, the flame, after passing under the boiler, returns through the central flues, passes thence along one of the side flues, traverses the end of the boiler along the other side flue, and then along another flue parallel to the boiler, but not contiguous with it, to the chimney.

Safety of
boilers.

(184.) *On the safety of boilers, and the accidents to which they are liable.*—Steam engines may certainly be considered as the highest effort of human industry, but it is of the greatest importance that they should be safe: unfortunately, we have frequently the most terrific acci-

dents occurring, which it is necessary to guard against and prevent; these are, of course, more common in the boilers of high than of low pressure engines, but they have occurred in both, and the consequences attending them have been very terrible. To devise a sure means of preventing such accidents it must be confessed is a problem that has not yet been completely solved, although it has excited the attention of men of Science and of the most intelligent practical engineers; amongst the former M. Arago has entered upon this inquiry, and has separated these accidents under different heads, and traced them to different causes. The most common accident is when the power of the steam is allowed, either by neglect or design, to accumulate, till, exceeding the strength of the metal, the boiler is destroyed from internal explosion. In general, a proper constructed safety valve is supposed to be a remedy for this evil; but cases have occurred in which the boiler has burst immediately after opening the safety valve, as if the relief given to the boiler had been the cause of the accident, by producing an additional expansive power in the steam.

This appears very extraordinary, *i. e.* that relieving the boiler of a part of its pressure should increase the expansion of the part remaining; the fact, however, has been accounted for by Mr. Perkins as follows. He supposes that in such cases the boiler has not been supplied with sufficient water, and that the part of the boiler immediately above the water becomes red hot; this heat is communicated to the steam, and increases its elasticity, but not according to the laws of elasticity of steam in contact with water, that is, he supposes it to increase its elasticity but not its density; but now the safety valve being opened, the water of the boiler is agitated, the surface water is driven up against the red-hot boiler, its density is thereby suddenly increased to a degree greater than can be sufficiently relieved at the common safety valve, and explosion follows. It has been suggested, however, by Mr. P.W. Barlow, that the latter part of the above hypothesis is not entirely correct; that it is more probable that the water thus driven against the red-hot iron is decomposed, the oxygen being absorbed and hydrogen formed in such quantities as sufficiently to account for all the consequences which follow. The provision against this cause of accident, supposing the above hypothesis or either of them correct, is by paying proper and particular attention to the feeding pipe and apparatus.

Another species of accident which has occurred to steam boilers is when a diminution of elastic force has preceded the explosion. M. Arago has reported some accidents of this kind:—"A boiler," he says, "constructed to produce low pressure steam, exploded in the midst of a manufactory, immediately after a large discharging cock had been opened, through which the vapour began to escape with rapidity. To open a stop cock or raise the safety valve is evidently one and the same thing; the explosion in this case, therefore, was determined by an operation that it would seem ought to have prevented it. This fact," M. Arago observes, "however strange it may appear, must be received with the utmost confidence, when it is stated that I received it from Mr. Gensoul of Lyons, and that this able engineer was an eye-witness of the accident. If in an extreme case, such as that just mentioned, the opening of a valve may bring on the bursting of the boiler, it must frequently happen that such an opening, without occasioning an accident, may, notwithstanding, give rise to a sensible and sudden increase in the elastic force of the vapour."

Machinery.

Manufactures.

The phenomenon within such limits may be studied without danger. I am aware that the experiment has been made at Lyons, and that in a little high pressure boiler, as soon as a discharging cock was opened, the safety valve rose also. M. Dulong and myself have, on the other hand, always observed that a diminution of tension accompanies the opening of the valves. But I do not on that account regard the experiment made at Lyons as less certain, since it has for witnesses M. Tabareau, Director of the School of La Martiniere, and M. Rey, Professor of Chemistry." No probable explanation is here offered by M. Arago; but it would necessarily happen that if any stoppage took place in the feed pipe till the boiler got red hot, as supposed in the last case, and that suddenly this pipe opened, that the introduction of water would first reduce the elasticity of steam, but immediately after the water rising to the red-hot part a sudden expansion or decomposition would take place, and a consequent explosion. Another kind of accident, frequently attended with very fatal consequence, is the collapse of boilers from external pressure. On this head M. Arago observes, "Boilers made of sheet copper or wrought iron, and those in particular that work with low pressure steam, suffer under certain circumstances from accidents precisely the reverse of those we have hitherto spoken of."

These boilers occasionally collapse completely, their sides being suddenly bent or crushed inwards. The cities of Lyons and St. Etienne have recently been the theatres of several accidents of this kind; and it is necessary to be protected against them, were there no other object than to prevent considerable manufactories from being suddenly reduced to a state of inactivity.

The lesser cylinders, which in some cases form internal fire-places and flues, also collapse occasionally. Their sides being unable, under certain circumstances, to resist the pressure contained in the circular space that surrounds them, they give way and flatten suddenly. And as this cannot take place unless the metal gives way in some part, the boiling water spreads in torrents through the adjacent apartments, and often produces serious accidents. Mr. John Taylor, F.R.S. has furnished the following instance of this kind of accident.

At Mold mines, in Flintshire, there is a large steam engine driven by three boilers with internal furnaces. On a certain day the Machine had been stopped for about five minutes; the fireman had already shut the doors of all the three furnaces, closed the dampers of two of the chimneys, and was in the act of closing that of the third, but hardly had the metallic plate reached its place when he saw a gust of flame dart from the fire-place, and an explosion followed instantly. Two workmen who were unfortunately in the direction in which the boiling water was projected were instantly killed.

A close examination of the boiler showed, that the outer cylinder had neither moved from its place nor sustained any damage. Even the weight suspended to the lever of the safety valve was still in its place after the accident. Neither had the less cylinder been moved from its place, but was so flattened by the crushing of its sides, that the hand could not be introduced between the plates.

The proper remedy for this accident is the interior safety valve, as described in a subsequent section.

Other accidents peculiar to boilers with interior furnaces are pointed out by the same author. A little consideration, it is observed, of the numerous causes that may bring about the explosion of a boiler, and on

Machinery
the various combinations of which they are susceptible, will show that it is hardly possible to obtain invariable rules in respect to them. It may, however, be remarked as a general law, that the figure of the boiler is the preponderating cause, and that it is upon it that the species of bursting that takes place most frequently depend. It is in this point of view that detailed and complete accounts of the accidents that daily happen would be of great use. We may now assert, in consequence of the valuable investigations published by Mr. Taylor, that in boilers with interior furnaces or flues passing through them, the surface of the inner cylinders must be considered as the weakest part.

After the almost simultaneous explosion of two boilers at the tin mine Palgooth, it was found that the inner cylinders of both boilers were twisted upon themselves and torn in a great number of places. At the mine of East Erennis, the inner cylinder was not only flattened by the approach of its upper and lower surfaces, but had been thrown out of the building with great force, while the outer cylinder had not been moved from its place or sustained any important injury. We have already mentioned another example still more remarkable, of the complete change of shape and breaking of the less cylinder, while the outer one remained unaffected.

To this list may be added the recent fatal explosions of the Helen M'Gregor on the Ohio, and the Chief Justice Marshall on the Hudson, in both which cases the accident took place at the instant of setting the engine in motion; and in the latter, the safety valve was open, and the steam escaping freely by it.

In a subsequent page we shall give an abstract of a Parliamentary inquiry instituted with a view of devising some means of insuring the safety of steam engine boilers, particularly those employed in steam vessels. At present our object is to describe the several appendages to the steam boiler, of which a general view has been taken in the leading part of this Chapter.

(185.) *Safety valves.*—The external safety valve was first employed by Papin in his digester; it was afterwards adopted by Savery, and is still used in nearly the same form in a great many engines, although various forms have been proposed by different makers. The kind here alluded to is what is called the steel-yard safety valve. The construction is very obvious: a support projects from the side of a short tube, to which a lever is attached, carrying a weight at its other end, and to the lever is fixed the valve which opens when the pressure of the steam from within exceeds that to which the weight is adjusted, or rather to the part of the lever to which the weight is appended. This is theoretically all that is required; but the weight by accident may be displaced, and the valve itself by corrosion may adhere to its seat, or the weight, through the ignorance of strangers, or the daring of the engineer, may be increased; cases which have too frequently occurred, and caused the sacrifice of the lives of a great number of persons. A very melancholy accident of this kind occurred a few years back in one of the boats on the Norwich River, which killed on the spot thirteen individuals, and scalded and maimed many others. This led to a Parliamentary inquiry into the subject, and various contrivances have been had recourse to to prevent the sticking of the valve; for the rest, the only remedy appears to be to have a box or cover over the valve, to be accessible only by the engineer. A different form of safety valve is shown externally in the boiler at W, pl. xi. the steam ascending the rising pipe.

Manufac-
tures.

Self-acting
feeder.
Pl. xi.
Fig. 1, 2.

Self-acting
damper.

Gauge
cocks.

Self-feeding
furnace.

which is carried into the open air; but the steel-yard valve is represented in the internal valve at V.

(186.) *Self-acting feeder*.—This is represented in plate xi. E is a pipe rising from the boiler, having a cistern at its upper part; this cistern is constantly supplied with water by the engine from the hot-water well; at the bottom of the cistern is a valve opening downwards, but which is kept shut, while the boiler has a proper supply of water by the following contrivance. A stud projects above the edge of the cistern, on which is supported a lever carrying a weight at one end while to the other is suspended a small wire rod, which, passing through a stuffing box, descends into the boiler; to the end of this is hung in the water of the boiler, what is called a stone float; that is, a large stone, which is so balanced by the weight as merely to float on the surface of the water, and of course to rise and fall with it. When the water, therefore, sinks in the boiler the stone sinks with it, which raises the balance weight, and with it the feed valve; hence the water in the cistern descends the pipe, and is sometimes carried by it to the bottom of the boiler and along its bottom, in order that it may receive some heat in its passage, before mixing with the general mass. This water, thus supplied, is furnished from the hot well, and generally enters at about the temperature of 100° through the horizontal pipe s s.

(187.) *Self-acting damper*.—This adjustment takes place through the feed pipe, and is thus managed. A central tube rises in the feed cistern, so as to have a way into the feed pipe without deranging the feed valve. In the pipe itself is hung a weight less in diameter than the bore: this weight is suspended by a chain, which, passing over two pulleys, has the damper D hung from its other end, which, working in two iron grooves, is free to ascend or descend. The weight in the tube being such as just to balance it, together with the friction of the chain pulleys, &c. when immersed to a certain depth in the water of the tube, forced up into it above the level of the boiler by the pressure of the steam. Suppose now the damper properly adjusted to the elasticity of the steam, equal to a certain amount of pressure, and that the weight and damper are in equilibrio and at rest. In this state they will remain until some change in the state of the steam arises. Suppose its elasticity to be increased, this will force the water higher up in the tube, the relative gravity of the weight will be diminished, and the damper descends, and thereby checks the draught of the flue, and of consequence the intensity of the fire. On the other hand, if the elasticity diminish, the water sinks, and the weight with it; this rises the damper, increases the draught, and at the same time the combustion of the fuel.

(188.) *The gauge cocks*.—These are represented at Z; their situation, however, is not important. One of these will be seen with its end just above the surface of the water, and if opened will of course furnish only a supply of steam, but the other, if opened, will yield water; therefore when this happens the water is at its proper level; but if both cocks supply water, this is too high in the boiler, and if both yield steam the water is too low, and either circumstance requires the attention of the engineer.

(189.) *Self-feeding furnace*.—We have above described all the usual appendages to a steam boiler, but with all these the furnace still requires the attendance of the stoker, but even the service of this individual has been in great measure dispensed with by one or two very ingenious contrivances. The first was proposed by Mr. Brunton,

a highly ingenious engineer of Birmingham. In this furnace the grate is circular, and is made to revolve horizontally beneath the boiler, by which means the heat is uniformly distributed over the whole of the lower surface, and a regular supply of coals is furnished from a hopper above. To effect this, the axis upon which the grate turns is connected with the steam engine, from which it derives its rotation, and for a cylindric boiler of five feet diameter it is made to perform about one revolution per minute. In its rotation every time it arrives at a certain point, the channel from the coal hopper is opened and a supply of coals is obtained. In order to prevent the air from passing down with the coals into the furnace, the patentee describes in his specification a rim, upon which the regulator is intended to lie descending into a trough, for the purpose of forming a water or sand valve. There is also a regulator to the feeder connected with the damper, so that if the boiler becomes too hot, or the pressure of the steam increase, the quantity to be supplied should be diminished in a proportionate degree.

Another self-acting furnace is likewise sometimes employed; this also has a hopper near the mouth of the furnace, through which coals, first broke down to a proper size, by passing between two rough or studded rollers, fall in a gradual and continued stream; below this aperture in the hopper, and in front of the furnace, are two iron circular plates, revolving with a very great velocity; and as the small lumps of coals fall on these plates, they are cast and scattered over the whole surface, whereby the fire is fed with fuel in a very equal and uniform manner, and by such continuous and small quantities, that much of the smoke which arises in common furnaces is destroyed.

(190.) *Steam gauge*.—To ascertain the pressure of the steam with greater accuracy than can be done by the load on the safety valve, recourse is had to a barometer gauge G, attached either to the boiler or to some tube immediately in its vicinity, and in open connection with it. The usual form of this is that of an inverted syphon or bent tube either of glass or iron, one leg of which is joined to the steam pipe, and the other open to the atmosphere. A quantity of mercury being poured into the tube, it will, when the steam has exactly the same elasticity of the atmosphere, stand at equal height in each leg, these being both in this case subject to equal pressure; but if the elasticity of the steam exceeds that of the atmosphere, the mercury in the steam leg will descend, and that in the opposite leg rise, and the difference between the level of the two will be the excess of the steam pressure above the atmosphere, and half these number of inches will be about the excess in pounds per inch. On the contrary, if the steam is under atmospheric pressure, the difference will be seen by the depression of the mercury in the leg exposed to the atmosphere.

When the tube is of glass, the difference may be read off by looking to the columns themselves, but when of iron, a rod is inserted in the open end, and is graduated above, the rod rising or falling with the mercury. But in this case, the divisions, which are numbered for inches, must be only half inches, because a rising of half an inch in one leg is produced by a corresponding fall in the other leg of the same amount, making one inch difference.

(191.) *Man hole*.—This is an aperture in every boiler large enough to admit a man to descend to clean the boiler or for any other purpose; it is shown in the figure at M, having the internal safety valve V in its surface. This, after cleaning or repairing any internal parts, is securely

Machinery.

Manufactures. fixed down by screws and nuts, and carefully luted all round to render it steam tight. T T is the pipe for conducting the steam to the engine.

Of Steam Pipes and Cylinders ; illustrating the general Principles of Action in Single and Double Acting Engines.

Steam pipes, valves, &c. (192.) It has been stated that great changes have taken place in the construction and arrangement of valves, steam pipes, &c., since the first introduction of the steam engine, properly so called, by Watt, and that there are at present a great variety of forms made use of by different makers. It will not, of course, be expected we should enter into a full description of these matters ; it will, however, be rather interesting to explain one of the earliest methods, although not the best, by which the operation of working the valves was effected ; we shall then show an example or two of the most recent and most improved methods. First, however, as this article is intended to furnish rather a popular description of the steam engine, than an article for practical engineers to consult, we propose to explain the general principle from which the motion is derived.

Steam valves, condensers, and single acting engine. Pl. xii. Fig. 1. Fig. 1. plate xii. represents a section through the cylinder, steam pipe, condenser, air pump, condensing cistern, and hot well, of a single acting engine, viz. an engine in which the piston is only acted upon during the down stroke, being returned from the bottom to the top of the cylinder merely by a counterweight, placed for the purpose on the other extremity of the beam. In this figure C is the cylinder, P the piston, E the steam pipe, B the condenser, A the air pump, K the hot well, H the blow valve, R is the rod of the piston passing through a stuffing box at R, to render the cylinder steam tight ; S is the pipe through which the steam is admitted to the cylinder, and V D the pipe or passage through which it is afterwards passed to the condenser ; G is a passage between the condenser and air pump, in which is a valve G, shutting towards the condenser, and *a*, *b*, *c* are three other valves ; *c* opening or closing the passage between the steam induction pipe S and the cylinder C ; *b* opening or closing the pipe or passage E, which forms a communication between the top and bottom of the cylinder ; and *a* opening or closing the eduction pipe D, by which communication is made between the cylinder and condenser. L is a cock which admits a jet of water into the condenser, and O is a passage by which the condensed steam and injection water is discharged from the pump A to the hot well K, to be from thence, by another pump, returned again to the boiler.

In the position in which the piston is shown, it has just begun its down stroke ; the valve *b* is closed, and *c* open, so that the steam from the boiler is pressing upon the top of the cylinder and carrying it downwards, the valve *a* being up, whereby the steam in the cylinder is open to the condenser ; which, as it rushes in, is immediately condensed, whereby the pressure of the steam above the piston becomes effective, and it would be so to its whole amount if the vapour in the condenser could be entirely annihilated ; but some elasticity always remains in this vapour, and the piston is therefore urged on by a force equal to the difference between the elasticity of the steam and vapour. Conceive, now, the piston to have descended to the bottom of the cylinder, the valve *c* to be closed, thereby intercepting the passage of the steam from the boiler to the cylinder, and at the same

Machinery. time the valve *a* to be closed, and *b* opened, then the communication being opened between the two ends of the cylinder, and the induction and eduction valves being both closed, the piston is in a state of equilibrium, and the counterweight at the other end of the beam will return it to the top of the cylinder ; being arrived there, the induction and eduction valves are opened, and the equilibrium valve *b* is closed, the condensation is renewed, and the piston again descends. The pump A, worked by the engine, continually drawing off the water of condensation, condensing water, and the air brought into the condenser with it.

In double acting engines the condensing jet is constantly playing into the condenser, but in single acting engines it is frequently suspended during the up stroke of the cylinder, in which case the cock L is alternately opened and shut by a part of the working gear. This is sufficient to give a general idea of the nature of the operation in a single acting engine ; but we have said nothing relative to the methods by which the valves *a*, *b*, *c* and cock L are opened and shut, which in their simplest shape become very complicated. If the stroke of the engine could be always maintained of the same length, and the engine were not worked expansively, nothing could be more simple. We have only to conceive the three valves fixed upon one rod, at proper distances, passing through a stuffing box O, and that this rod is lifted and depressed at every stroke, so as alternately to close the valve *b* and open *a* and *c*, and then to close *a* and *c* and open *b*, whereby the action would be continued ; but it is necessary that these valves act independently, and hence arises considerable complication which it will be our object to explain.

(193.) When there are rotary parts in an engine, the Method of opening and shutting the valves is commonly effected by opening and closing the valves. means of eccentrics, but in others by a rod or beam, called a plug tree, which is attached to the engine beam, near to the end moved by the piston rod. This plug tree is provided with adjustable plugs or tappets, as at *f* and *d*, fig. 2, which strike the levers or handles of the valves, and thus open and shut them at the proper intervals as the beam ascends or descends, and these intervals are adjustable to the greatest accuracy, by a corresponding adjustment in the situation of the tappets.

In general, modern engines are furnished with valves, working through stuffing boxes, as shown in fig. 2 ; Fig. 2. but in others, commonly those of earlier date, the stuffing box is in the side, as is described below. As it is most important that the several valves should open and shut at proper times, great attention is paid to this part of the operation. When lifting valves are employed, they are generally opened by weights ; thus a weight *w*, sufficient to overcome the friction and open the valve, acts by a short arm *a* on the axle which requires to be turned to move the valve ; this weight is kept suspended by a spring catch *b* while the valve is closed, and when the catch is disengaged by the handle *c*, being moved by the tappet *d*, the valve opens, which if large requires considerable force acting as it does against the pressure of the steam ; in these cases, however, valves of a particular form, or other means are had recourse to, to facilitate the operation. In some engines the valves are opened as well as shut by the motion of the engine itself, but weights have hitherto been preferred, as they are conceived to open valves more rapidly than when acted upon by the moving gear : it certainly, however, leads to greater complication ; for it is not only neces-

Manufac-
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sary that the weight should open the valve rapidly, but the fall of the weight must be afterwards regulated, at least it is thought to be necessary in many cases. In these it either descends into, or forces a piston into a vessel of water, *c*, while the aperture by which the water escapes from under it may be increased or diminished at pleasure; the weight, therefore, acts with its full weight to open the valve, but as soon after as it begins to move, it is retarded by the water till it is finally stopped, and, during the ascent, a valve opens inwardly at the bottom of the vessel, and, therefore, the engine has no more than the weight to raise again. Our figure and description here have only reference to one valve, but there are three, besides the injection cork, which must be provided for.

The preceding illustration will, however, facilitate the comprehension of the following explanation, in which, to show Watt's early method of working, the valves are represented as turning on axles passing through stuffing boxes in the sides of the vessels, being the actual mode of operation adopted in the single acting engine described in a subsequent article.

A different
method of
working
the valves.
Fig. 3.

(194.) *Steam pipes and valves.*—The cylinder, steam pipe, and valves referred to above are represented in fig. 3, where A is a section of the cylinder, in which the piston H moves, F the steam pipe proceeding from the boiler, and Q the pipe descending to the condenser L. N is the air pump, *m* the passage or pipe from the pump N to the condenser L, in which passage is an occasional communication by a hanging valve at *m*, which shuts towards the condenser; *l* is the injection valve, to be lifted by the engine at every stroke, for the purpose of condensing the steam; *w* is the snifting or blowing valve placed outside the condensing cistern M. This valve communicates with the condenser by a pipe passing through the side of the cistern M. K is the exhaustion valve, to be lifted by the engine, and thus to open a communication between the cylinder and condenser. O is the steam valve, called the equilibrium valve, also to be lifted by the engine, and opening a communication between the upper and lower part of the cylinder through the steam pipe *r*. F is an upper steam valve of the same kind, opening a passage between the boiler and top of the cylinder, and thence by the pipe *r* and valves O K to all parts of the engine.

The valves are lifted by means of a lever applied to each, within the iron box in which it is contained, entering into an opening in the stem of the valve, and a second lever is fixed on the axle of the first on the outside, to be connected with the lever and handles *x*, *y*, *z*, which open and shut the valves. There are three separate axles or spindles placed parallel and above one another, having each a handle as above described, by which it is moved either by hand to start the engine, or by tappets on the plug beam R, when the engine is in action.

The two upper spindles have short back levers pointing towards the cylinder, from which rods are suspended, with a sufficient weight *o* to turn round the spindles and to cause the handles to rise. The lower spindle has also a lever projecting from it, but in an opposite or forward direction, with a heavy weight *n* fixed at its end, which causes the handle to descend. The axles of the lower handles have small levers or catches, fig. *a*, which act in the hooks of a double hatch or detent, which is movable upon a centre pin situated between the two axles. The hooks of this detent are to detain the catches of the spindles, and to prevent the handles *y*, *z* from

Machinery
moving by the weights till the detent is moved on its centre, so as to relieve the catches of the levers from the hooks *t*, *v*; but it is evident that when only one catch is hooked, as 2, by the lower hook *v* of the detent, if the other catch 1 is moved by depressing its handle *y*, it will press the end *t* of the detent forward upon its centre, which at the same time pressing back the hook *v*, releases the catch 2 of the lower handle, and the weight *n* on the spindle immediately falls.

The upper handle is employed to open and shut the valve F, having a lever which communicates, by a rod 2, with the lever 3, so that by pressing down the handle it shuts the valve F. The weight attached to this handle tends to open the same valve, so that when the handle is depressed the valve will be shut, and when the weight acts it will be open. A very similar operation will readily be traced to the valve K, acted upon by the second handle *y*. The lower spindle *z* has a different action on the valve O, which is opened by the rod 14, when the handle is allowed to fall down and shut when it is held up.

The upper spindle has no detent to detain it, but the rod 5 has an equivalent effect. This is jointed to the middle axle, which has its rod and weight *o* suspended from it. In the upper end of rod 5 is a loop in which works a pin, at the end of lever 6, projecting from the upper axis towards the cylinder, whereby, while the middle axis is detained by its catch and detent *t*, keeping the exhausting valve K shut, the valve F will be shut also; but when the catch 1 *t* is discharged, and its weight has opened the exhausting valve, the looped rod 5 will no longer support the lever 6 of the upper axis, and its weight descending will immediately open the steam valve F. It is to be observed, however, that the valve F is not necessarily open when K is open, as the upper one may be shut by depressing the handle *x* without acting at all upon the valve *h*, the slit in the rod 5 allowing this action, which is an essential condition when the engine acts by expansion.

From the injection valve *l* a long wire ascends; this is attached to a strap 9, which winds upon the middle axle, whereby, when the middle handle flies up by its weight, it winds up the strap, and opens the injection valve at the same time with the exhausting valve.

This injection valve closes and opens the orifice at the end of a short curved pipe proceeding from the condenser, which pipe has a cock in it, between the valve and condenser, to cut off and regulate the supply of injection when the cock is open.

It must be acknowledged there is considerable complication in this arrangement; it has been, however, found to be effective; but it is rather given here to show the progress made within a short period, and will serve to put in a stronger light some of the methods now generally adopted. Our object being not so much to give information to those engaged in constructions of this kind, as to point out to the general reader the successive steps which have brought, it is presumed, nearly to perfection, one of the noblest efforts of human ingenuity.

(195.) *Steam pipes and valves in double acting engines.* Steam pipes and valves in double acting engines.
—It has been stated that different masters vary considerably in their methods of working the valves. In fig. 4, we have given a section of the steam ways and valves employed by Messrs. Fenton and Murray; the cylinder itself is not shown, but it will be understood to be supplied by steam through the passages whose sections are shown black at the top and bottom of the figure. C is the steam pipe proceeding from the boiler, and furnished

Manufac-
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with what is called a throttle valve at *a*, to regulate the supply of steam to the engine. This is acted upon by the motion of the lever *b*, and connecting rod *c*, which communicates the action of the governor *g* to the valve *a*; the governor itself receiving its rotation by means of a band passing over a pulley on the crank shaft to a similar pulley on the axle of the governor; *ee* are two levers passing through a slit in the middle of the spindle and turn upon an axle at *f*. The upper part of the spindle is furnished with a socket *h*, which is connected to the lever by rods *ii*; this socket ascends when the centrifugal force raises the governor balls; and, on the contrary, when the motion is slow, and the balls descend, the socket *h* also descends and lever *l* moves with it. *c* is a rod connecting the levers *l* and *b*, which by their joint action communicate the motion of the governor to the throttle valve *a*; so that when the steam engine is at rest the balls *jj* will also be resting against the arms *kk*, the upper end of the levers *ee* will be brought nearer to each other, and the rod *c* being raised, the throttle valve will be turned in a horizontal direction, thus allowing a large portion of steam to pass through the pipe *C*; but after so much has passed as is required, and the engine is put in motion, the balls fly open, the socket *h* and connecting rod *c* ascend, and the valve is brought into an oblique position, shutting or contracting the orifice as the speed increases, which thereby contracts the supply, and checks the speed, so that being once properly regulated, the speed is continued nearly uniform. This action, which it was proper to describe, has no reference to the valves employed for working the engine, as described in the preceding article. These may, however, now be readily explained. The proper supply of steam being admitted to pass through the pipe *C*, it passes through the pipe *a* to either top or bottom of the cylinder, *viz.* to the top of the cylinder, when the valve at *n* is open, and that at *o* shut, or to the bottom, when the latter is open, and the former shut. *E* is the eduction pipe, passing down to the condenser, this pipe being opened alternately to the top and bottom of the cylinder, by means of the valves *p, q*. The valves *n, o* have each a cylindrical tube or spindle passing through the stuffing boxes *r* and *s*. The upper end of each of these has a stuffing, the upper one at *t*, the other at *u*, for the rods of the valves *p, q*, which open to the eduction pipe as above stated, so that either the steam or eduction valves may be opened without permitting the steam to escape.

Fig. 5.

Fig. 5 is a front view of the two sliding rods which give motion to the valves *n, o, p, q*: these rods are kept in a vertical direction by the pieces *z z*, and the guide *l*; the lower end of the rods have friction rollers *3, 3*, which are acted upon by two eccentric pieces *4, 4*, on the horizontal shaft *Z*, which derives its motion from the shaft *Y*, placed at right angles to, and communicating by means of bevelled wheels with, the crank shaft of the engine. Four arms, *9, 10, 11, 12*, are fixed to the rods *vv* and *ww*, for the purpose of moving the valves, and a lever or handle, *13*, turning on a pin screwed on the pipe *E*, is used to open and shut the steam valves when the engine is first set to work, as will be hereafter described. At present, it will be seen that, when the steam valve *n* is open, the eduction valve *q* is also open, the vacuum is then forming below the piston, and the pressure of the steam being applied above this descends. These two valves being now closed, and the steam valve *o* and eduction valve *p* open, the top of the

VOL. VII.

cylinder is open to the condenser, and the bottom to the steam, whereby it ascends with a force equal to that with which it descended, except only the weight of the piston this being in one case additive, and in the other subtractive. The reader will at once perceive the great simplicity of this arrangement in the double, as compared with that of the single acting engine, as above described.

The parts of the figure marked *18, 19, &c., 22, 23, &c.*, are gauges for ascertaining the state of the cylinder and condenser, and are described in a subsequent article.

(196.) *Sliding valves for a double acting engine.*—Here *F* (fig. 6) is the induction pipe, and *D* the eduction pipe, leading to the condenser by means of the passage *G*; *a, b, c, d* is the slide containing a passage *E* through it, and a spindle or rod *O*, by which it is elevated or depressed; the whole slide, as appears from the figure, being less than the length of the cylinder. There are two faces or slide valves at *a* and *c*, which are perfectly smooth and level, and work against equally level faces *e, f*, attached to the side of the cylinder. Between *a* and *c* is a space left or cut away in the slide, so that the steam entering the sliding case at *S*, encompasses it all round except where it is parted at *g* and *h*; the slider being, as shown in the figure, in its highest position. The steam entering at *S*, enters the steam cylinder at the top by the passage or pipe *F*, at which time also the bottom of the cylinder is open to the condenser. The piston, therefore, is now descending, and at a certain portion of its descent, the face *a* closes the aperture *F*, before the face *c* has closed that at *D*; the top of the cylinder is, therefore, shut off from the steam, while the bottom is still open to the condenser. From this time to the bottom of the stroke the steam is acting expansively. The slide having, however, now descended to its lowest position, the aperture *D* is open to the steam entering at *S*, while the slide being now wholly below the passage *F*, that passage is opened to the condenser through the passage *E*, and the piston ascends, by precisely a similar force to that by which it descended, the steam acting expansively during that part of the stroke when the aperture at *D* is shut by the slide *c*.

This is an extremely simple process, and by the whole slider being surrounded with steam, the objection made sometimes to sliding valves, *viz.* the friction to which they are exposed by the unequal pressure on their two sides, is in a great measure avoided; but there was still a great defect irremediable in the packed slide, from the inequality of the packing, which causes an abrasion to be constantly, although slowly, going on, which destroys the faces both of the slider and of the surface on which it slides. We have seen a valve of this kind, which after a few years' wear, had become completely furrowed and worn round, as well as the sliding surface on which it slid; a defect, however, which has been remedied by Mr. Hague, to whom we have several times referred. The motion of this valve is effected by a method very similar to that last described, that is, by eccentrics and levers.

A great variety of methods, besides those above explained, and numerous valves, slides, and cocks have been invented, which would require great space to describe; those above given will, however, furnish the reader with a tolerable idea of the process of supplying and discharging the cylinder of its steam. For more on the subject the reader may consult the Treatises on the Steam Engine by Farey and Tredgold.

Machinery.

Of sliding
valves.
Fig. 6.

Manufac-
tures.

Pistons.

(197.) *Pistons*.—The general reader finds no difficulty in conceiving the nature of the piston; he has only to imagine a truly cylindrical plug, fitting very exactly the bore of the cylinder, but the practical engineer knows the difficulty of putting this idea into practice; it is by no means an easy matter to fit the piston so close as to render the cylinder steam tight, and yet such as to produce little friction between the piston and side of the cylinder. This was one of Watt's first difficulties; the pistons before his time having been kept close by water floating on the upper surface. After many experiments on the nature of different packings, and different unguents for destroying the friction, he finally determined that hemp or tow answered best for the purpose, when lubricated with tallow. According to the best practice of the present day, after all the improvements in boring, &c., the friction is generally estimated in hemp packed pistons at 288 pounds per foot on the contact surface of the piston. With this drawback on the power of the engine it is natural to suppose that great exertions would be made, and great ingenuity called into action to reduce this retarding effect as much as possible, still preserving sufficient contact to secure the steam from escaping.

Hemp
packed
piston.

(198.) *Hemp packed piston*.—This is differently constructed, but a very common form is shown in plate xii. fig. 3, within the cylinder. The bottom of the piston is first fitted as accurately to the cylinder as possible, leaving it at full liberty to rise and fall through the whole length; the part of the cylinder immediately above this is from one to two inches, according to the size of the engine, less all round than the cylinder, to leave a circular or annular space, into which unspun long hemp, or soft prepared rope, is wound as evenly and compactly as possible, to form the packing. This being done, a plate or cover is put over the top, having a projecting ring to fit over the lower part to complete the upper side of the space for packing, being compressed upon it by means of several screws seen in the figure. Both the upper and lower part of the space round the piston to contain the packing is a little curved, that the pressure produced by the screws on the packing may force it against the inside surface of the cylinder into as close contact as possible.

After some time the packing wears so as to go too free, and to suffer the steam to escape; in this case the top of the cylinder must be removed and the screws tightened, which again presses the hemp towards the sides, and restores the proper degree of contact; and this is repeated till no useful effect can any longer be produced in this way. When this happens the piston must be repacked. The piston rod is generally attached to the bottom part of the piston, by means of a conical end, which enters into a similar formed hole in the piston, which it exactly fits, and a screw nut or wedge between the bottom and top is inserted which effectually secures it.

Barton's
metallic
piston.

(199.) *Metallic expanding piston*.—There are a variety of pistons of this description, the first projector of them was Mr. Cartwright. They have, however, been improved upon by subsequent makers, and one by Mr. Barton, which is represented as originally projected by the inventor in plate xii. fig. 7, and in section within the cylinder fig. 6. The bottom plate of the piston is cast iron, and with it is cast the six arms with their projecting circular heads, in which are holes for screwing on the top of the piston, also of cast iron; these arms being formed merely for the sake of lightening the piston, which if the whole were solid would be very heavy.

The bottom and top plates are accurately turned, so as to fit the cylinder very nearly, and the upper side of the lower plate, and the under side of the upper plate are made very smooth by turning and grinding, and round the outside of the projecting radii is placed an iron hoop, also very truly turned; this hoop preserves the top and bottom of the piston, at a perfectly uniform distance all round. Now the space between the top and bottom plates is thus filled. A ring of gun metal (it was first proposed to use iron) the full size of the piston, and exceeding the thickness of the space between the plates, is cut into four segments, denoted by *e, e, e, e*, of the form shown in the figure, between each two of which are triangular pieces of the same metal. These segments and wedges are nicely ground so as to slide very truly between the top and bottom plates above described, which, as already stated, are also ground with very great care. Behind the triangular wedges are placed properly tempered steel spiral springs, which acting against the hoop above described, and the base of the wedges, force these outwards, and cause the segments to expand, the points of the wedges also advancing to fill the little space between them; by this means the cylinder, when very true, is beautifully filled by the piston, and after a little wearing works with a smoothness and freedom scarcely to be obtained in any other way; the cylinder and piston each acquiring the most perfect and delicate polish.

Machinery.

Lately Mr. Barton has discontinued using the spiral springs which were liable to derangement, and has supplied their place by one strong steel spring like a hoop, the ends slightly overlapping; this, by expanding, presses upon all the bases of the wedges, and thus performs the same office as the spiral springs and in a more simple and effectual manner. The breadth of this hoop is of course equal to the depth of the wedges and segments.

It may be remarked, that to save weight the segments and wedges are not solid metal; their section being as shown in the side figure. The piston is perforated with a conical hole to receive a similar formed solid head at the bottom of the piston rod, which may be secured thereon by any of the usual methods.

It should have been observed, in describing the original form, that the segments were in two thicknesses, as shown in the section, and were made to break joint with each other; only two springs are therefore seen, the lower part showing only the empty cavity of the segment. The spring is attempted to be so adjusted as to bring on a pressure of about four pounds per square inch between the cylinder and piston; this, according to the experiments we have recorded on friction, would not make the latter more than two-thirds of a pound per square inch, or 96 pounds per square foot, whereas the packed piston is estimated at 288 pounds. Of this calculated effect, however, there may be some doubt.

A great variety of other pistons have been projected and partially employed; and the reader who wishes to examine their construction, may consult those Works written exclusively on the steam engine; as, for example, the Treatises by Tredgold and Farey, in which are found many other very ingenious contrivances to secure contact, and at the same time to reduce the friction as much as possible.

(200.) *Of the cylinder and condenser gauges*.—In order to ascertain the state of the engine at any time, two barometer gauges are employed, one showing the elasticity

Manufac-
tures.
Description
of the baro-
meter
gauges.

of the steam in the boiler or in the cylinder, and the other the rarefaction of the vapour in the condenser. The cylinder gauge is exactly similar to that attached to the boiler already described, but is represented in fig. 4 as attached to the cylinder by 18, 19, 20, the part of the figure marked by these numbers being a glass or iron tube, as before explained, having a quantity of mercury inserted; this mercury, when the steam in the cylinder is just equal to that of the atmosphere, is equally pressed in both legs, and will therefore rise to the same height in each; when the steam in the cylinder has greater elasticity than the atmosphere, it will rise highest in the leg 18, and when the elasticity is less it will fall in this leg and rise in the other, so that under any circumstances, the power of the steam in the cylinder, or at least in the steam case leading to it, is very readily ascertained: it is sometimes rather less than at the boiler. The connection between the gauge and steam pipes may be cut off at pleasure, by means of the stop cock 19.

The condenser gauge acts a little differently, at least it requires a different form of tube; (see the part of the figure marked 21, 22, 23;) this consists of a bent iron tube 21, the lower end of which is open to the condenser. The mercury is poured into the tube at the open end 23, and the stop cock 22 being opened, the mercurial column at 23 will be depressed, while that on the opposite side will be raised in a proportionate degree. This effect is produced by the vacuum formed in the condenser. If the condenser and air pump are in good order, the mercury will descend about fourteen or fifteen inches, and rise in the other the same quantity, making a difference of thirty inches. This, however, would indicate a perfect vacuum. Generally, if this gauge show twenty-six or twenty-eight inches, the state of the condenser is very good. We have seen that the water in the condenser cannot have generally less than 100° temperature, (Art. 144.) and the vapour of water at this degree is equal to about two inches of mercury, so that it would be useless to aim at greater perfection.

Parallel
motion.

(201.) *Parallel motion.*—In the atmospheric engine, in which the piston was only effective during the descending stroke, the attachment of the piston to the arched head of the beam by a chain was made to answer the purpose of a parallel motion, the ascending motion having been produced by a counterweight. This was afterwards changed for a rack on the piston rod, and corresponding teeth in the arched head, which would thus perform the double stroke. These methods, however, in both cases, were at length superseded by Mr. Watt, by what he terms in his patent a *parallel motion*, and which, notwithstanding some change in its arrangement and variations in the proportion of its parts, has scarcely experienced any improvement.

First me-
thod.
Pl. x.
Fig. 6.

First method.—This is represented in pl. x. fig. 6, where ABH is the half beam, EP the piston rod or pump rod, which is required to move vertically, or nearly so, by the vibratory motion of the beam AB about its centre A. To effect this a rod or link BD is suspended from the point B, where it turns upon a movable joint; to the other end D of this link, another longer bar or link, called a bridle link, DC, is attached, also by a movable joint, its other end turning on a fixed point C. Let the parts be so arranged that the beam AB and the link CD are parallel when the beam is horizontal, at which time the connecting link BD may be conceived vertical, or nearly so. Then a point E may always be found in BD, depending upon the ratio of

the two radii CD and AB, such that, as the beam vibrates about its centre A, that point E shall ascend and descend vertically, or so nearly so as to answer every practical case.

When $CD = AB$, which is commonly the practical case, $BE = ED$, and to the point E the end of the piston rod is connected.

Some authors have bestowed a long mathematical investigation to determine the ratio of BE to ED, that of CD to AB being given, or conversely the ratio of CD to AB, that of BE to ED being known; but the proportion in either case is better found by construction.

When the proportion between AB and CD is given to find the point E, Mr. Tredgold gives the following rule: Let $AB : CD :: m : n$; then from the number n subtract half the square root of four times its square, minus 1 for a first number; also from the number m subtract half the square root of four times its square, minus 1 for a second number; then divide the first number by the first added to the second, and the quotient multiplied by BD the length of the link or bar, will give the distance of the point E from B; that is,

$$BE = \frac{BD \{ n - \sqrt{(n^2 - .25)} \}}{\{ m - \sqrt{(m^2 - .25)} \} + \{ n - \sqrt{(n^2 - .25)} \}}$$

It will readily be seen, that the motion thus produced, although nearly, is not strictly parallel, and therefore all that can be obtained is an approximation; but by fixing the proportions so that the point E may be in the same vertical in three positions, viz. when the beam is horizontal, and when it is nearly at the top and bottom of the stroke, the error out of these points will be very inconsiderable.

(202.) *Second method.*—Here again let AB, fig. 7, be the half beam, and to B and a point C in it towards the centre let two equal hanging links BD, CE be suspended, movable about B and C, and let their ends DE be also connected by a link $DE = BC$, and movable at those points; and again, let the angle E be connected by a bar or bridle lever EG, movable on the fixed centre G and at the angle E. Then the length of EG being taken such that D may fall as much short of the end of the beam when the latter is horizontal, as it falls beyond it at the top or bottom of its stroke, it is clear the point D will, by the motion of the beam, be made to ascend and descend nearly vertically, consequently the piston rod DP being connected with the parallelogram at the point D, this also will ascend and descend vertically as required. The proportion of the lever in this motion admits of great variation; the simplest case is when the radius AC is exactly half AB. Considerable latitude is, however, allowed to the workmen in the lengths of the links BD, CE, without sensibly deranging the parallel motion of the point D, and piston rod attached to it. With the proportions above stated, the centre G will fall upon the same line as the piston, which is often inconvenient, for as there are two parallelograms, one on each side of the beam, the centre of the lever EG cannot be made on one common axis. Eleven different proportions for these levers are given in the following Table, taken by Mr. Farey from actual measure from some of the best engines in and near the metropolis.

Machinery.

Manufactures.

TABLE of Proportional Radii for parallel Motion of the Second Class from actual Measure.

Number.	Length of stroke.	Length of half beam.	Coupling rod D E.	Links C E, B D.	Bridle Lever C E.
	Inches.	Inches.	Inches.	Inches.	Inches.
1	96	147	69	42	78
2	72	120	50	28	96
3	72	110	55	31½	55
4	48	60	41	20	60
5	48	84	38	19½	60
6	48	84	36	20	54
7	48	72	41	18	25
8	45.6	76	40	28	36
9	36	60	37	12	15½
10	24	37	16	9	26
11	23	36	16	12	26

The two great links of the parallel motion are each composed of a strap or loop of iron bent so as to form a double link, in the upper bend of which are two sockets for the pivots at the end of the beam, and at the lower end are two others for the pivots which project on each side the piston rod socket. The brasses of this joint are held in by wedges, put through the two links at the lower end, which, on being driven inwards, tighten the fittings to any degree required.

Other methods of producing parallel motion have been proposed by different constructors, some of which, applicable to other purposes as well as the steam engine, have been described in Art. 77, *et seq.*: Maudsley's mode of effecting this operation is by means of guides in an upright frame.

Description of a single acting engine.

Pl. xiii.

(203.) *Description of Watt's single acting engine.*—This engine was erected at the Chelsea water-works by Boulton and Watt, and has been referred to and described to illustrate the early principles employed by Watt in closing and opening the steam valves, the operation and proportions of the condenser, air pump, and other parts. Here F, pl. xiii. is the steam pipe connecting the boiler and cylinder, the former being enclosed in a case of brickwork, and the latter securely screwed down to the floor of the engine room by the bolts *nn*; its upper end is covered by a lid, through which the piston rod *a* slides in an air-tight box, called a stuffing box. The beam C A moves on its axis or gudgeon at B; and the bearings in which the gudgeons work are sustained by the floor and wall E.

The pump rod *p*, carrying a counterweight, is suspended at the end A of the beam; and both it and the piston rod *a* are connected by a parallel motion apparatus to the working beam C A.

The condensing cistern is at M, and contains the air pump N, the condenser, and hot well *g*; a continued supply of cold water is procured by the action of the cold water pump *y*, and the excess is carried off by a waste pipe to the well *q*; the whole of the external part of the apparatus being kept by that means at the lowest temperature possible.

The upper steam valve is at F, and the lower at *s*, and the exhaustion valve at O. These valves are moved by the plug tree R, which is furnished with tappets to give motion to the levers acting on the valves F, O.

The pump to raise water from the hot well *g* to supply the boiler is marked 20, and the water is conveyed by a pipe to the small cistern 14, on the top of the feed pipe, which is provided with a valve, and acted on by a lever connected by a wire passing down through a

stuffing box to a stone float (see Art. 186.) in the boiler, which by its descent opens the valve, and allows the admission of an additional supply of water when it is required. In order to prevent concussion, two blocks, 13, 13, are fixed across the upper side of the beam, and extend on each side so as to strike on four wooden springs on the floor which supports the beam.

Having as above described the several parts of the engine, let us now endeavour to illustrate its action. Conceive the fire lighted beneath the boilers; all the valves are kept shut by pressing down the two upper handles, *x* and *y*, and lifting up the lower one, their respective catches detaining them in those positions until the steam is sufficiently heated, and the engine is ready to work. In the quiescent position of the engine, when it is at rest, the counterweight always draws the piston fully at the top of its cylinder, as in the figure; the air pump bucket will also be at the top of its barrel.

In order to prepare for setting the engine to work, all the three valves must be opened at once. This is done by relieving the spindles from their several catches, when the weights immediately open the valves. The steam enters through the valve F into the top of the cylinder, and by the pipe *r* through the lower steam valve O, into the bottom of the cylinder, also through the exhausting valve K, into the condenser L, driving before it some air, which passes out at the snifting valve, not seen in the figure. At first, the coldness of the parts condenses all the steam which enters; and it is not until all the iron with which the steam comes in contact, is heated to the temperature of boiling water, that the steam ceases to flow from the boiler in a stream, and be condensed as it arrives at the cylinder and condenser; but after this the steam acquires the same force in the cylinder and pipes that it has in the boiler; it then occupies every cavity of the engine, and, in a little while, displaces all the air in the cylinder, condenser, and pipes, which passes out, and is discharged at the snifting valve. (See pl. xii. fig. 3.) This valve is always covered with water in a small cistern, attached to the side of the large one, to ensure its tightness. Through this valve the air is discharged by the steam, not at every stroke, as in Newcomen's engine, but only at first setting the engine to work, and this operation is called the *blowing through*. It is well known when the cylinder and other vessels are properly heated, and the air discharged, by a very smart crackling noise at the valve, like a violent decrepitation of salt in the fire, which noise is occasioned by the water in the small cistern producing a sudden and rapid condensation of the issuing steam when the air is all gone.

It being known by this sign that all parts of the engine are cleared of air, all the three valves are to be shut, by pressing and holding down the two upper handles *x* and *y*, and lifting up the lower handle *z*, in which situation its catch, 2, will retain it. This cuts off the further supply of steam from the boiler, and also intercepts the passage of the steam from the cylinder to the condenser; and as the cold surface of the condenser still continues to condense a considerable portion of steam, there will soon be none left, and a vacuum will be formed in the condenser, while the cylinder, both above and below the piston, is full of steam. The vacuum in the condenser will soon become perfect from the external cold alone, though more slowly than when an injection is made.

In this state the engine is prepared for starting at a

Machinery

Manufac-
tures.

moment's notice by the engine man letting the two upper handles *x* and *y* rise up by their respective weights; this opens the upper steam valve, and the exhausting and injection valves; the former admits the steam into the top of the cylinder, to press upon the piston, while the latter allows the steam already in the lower part of the cylinder to flow into the vacuous condenser; and at the same instant that he opens the injection cock, the valve is lifted, as also the exhausting valve; this admits a jet of cold water into the condenser, and condenses the steam as fast as it arrives from the cylinder, so that in an instant all the steam in the lower part of the cylinder will be drawn off and condensed. The pressure of the steam on the piston being now unbalanced by any thing beneath it, it descends and draws up the pump buckets and columns of water in the pumps, with a velocity proportioned to the pressure of the steam and the diameter of the piston compared with the height of the column of water in the pumps and the diameter of the bucket; but the piston having descended about one-third of its stroke, a chock or tappet of the plug frame *R* meets the upper handle *x*, and pressing it down, shuts off the steam from the boiler. That part of the handle on which the chock acts becomes perpendicular when the valve is shut, the handle being bent for that purpose; and the chock can, therefore, descend further, and slide against the perpendicular part of the handle, which is straight, without producing any further depression of the handle, at the same time that it keeps it down to the same point, so as to hold the valve shut. The piston, therefore, continues its descent by the further expansion of the steam at first let into the cylinder; but having arrived at the bottom of its stroke, a chock on the opposite side of the plug beam seizes the handle *y*, and presses it down, which pushes a rod 4, until it shuts the exhausting valve *K*, and also shuts the injection valve by the trap and rod 9. When the catch 1 (see pl. xii. fig. 3—*a*) of the handle *y* presses on the upper hook *t* of the detent *t v*, it relieves the catch 2 of the lower axle *z*, and then the weight *n* causes the handle *z* to fall, and pulling the rod 14, opens the lower steam valve *O*. Let us now consider the position of the engine. The middle handle *y* will be held down by its catch 1 holding in the upper hook *t* of the detent, so as to keep the exhausting valve *k* shut, and the upper steam valve *F* is also kept shut, by the same means which kept it shut during the latter two-thirds of the descent of the piston.

Under these circumstances the piston is at liberty to rise by the action of the counterweight *S*, because the opening of the lower steam valve *O* has established a free communication between the top and bottom of the cylinder, and the steam in the top of the cylinder can flow through the pipe *r*, and enter the bottom of the cylinder as fast as the piston rises by the action of the counterweight.

When the piston has returned to within one-third of the top of the cylinder, the chock of the plug frame quits the upper handle; but this handle cannot yet be thrown up by its weight to open the upper valve, because the rod 5, from the lever of the middle axis, bears up the short lever 6, of the upper axis, and thus the motion continues till the piston arrives very nearly at the top of the cylinder: a chock on the plug frame then seizes the lower handle *z*, and, lifting it up, shuts the lower steam valve; and the catch 2 of the lower axis passing the lower hook *v* of the detent, moves it on its

centre, so as to release the catch 1 of the middle axis from the upper hook *t* of the detent. This being the case, the weight of the middle axis causes its handle *y* to fly up, and by the rod 4 it opens the exhausting valve, and, by drawing the trap and rod 9, opens also the injection valve, at the same time the upper axis, losing the support of the rod 5, which kept it up, its weight carries up the upper handle, and by pulling the rod 2 it opens the upper steam valve *F*.

The steam from the boiler is now admitted to press upon the upper surface of the piston, while the steam from the lower part of the cylinder beneath the piston rushes into the condenser, where, being met by the cold injection, it is condensed, and makes a vacuum in the lower part of the cylinder, which brings down the piston to make another stroke.

At one-third of the descent the plug frame, as before, presses and holds down the upper handle, to keep the upper steam valve shut; and when the piston has arrived at the bottom, the plug frame presses down the middle handle *y*, to shut the injection and the exhausting valves; and in catching this discharges the lower axis, and the weight thereof opens the lower steam valve. The piston then rises by the counterweight, and when at the top of its stroke, the plug frame lifts the lower handle *z*, and shuts the lower steam valve, and in catching discharges the two other handles, which open the upper steam valve, the exhausting valve, and the injection valve, and this produces the descent of the piston, as before.

If the air has been fully discharged from all parts of the engine by blowing through, the action of the air pump does not begin until the injection water and the air which are extricated from the water in the boiling have accumulated in some quantity in the condenser; then at every descent of the bucket *d* of the air pump, it dips into the water contained in the bottom of the barrel *N*, and the water passes through the valves in the bucket; these valves shut when the bucket is drawn up, lifting all that water which is above them up to the top of the barrel, and there it is forced out through the hanging valve *g* into the hot well *g*. The drawing up of the bucket at the same time makes a vacuum in the pump barrel beneath it; and if this vacuum is more perfect than that in the condenser, which it will be if the condenser contains either air or steam, it will press by its elasticity upon the surface of the water in the lower part of the condenser, and force it through the hanging valve at *m*, into the lower part of the barrel *N* of the air pump; and when all the water is gone from the condenser, the air or elastic vapour which is in the condenser will follow and enter into the pump until the space of the barrel beneath the bucket is filled equally with the condenser.

This takes place while the pump bucket is at the top of the barrel; and on the descent of the bucket a space beneath it is diminished until it compresses this rarefied vapour so much, that its elasticity will be sufficient to close the hanging valve *m*, and to lift the valves in the bucket *d*, and pass through them into the space of the barrel above the bucket; and when the bucket has descended to the very lowest, the water contained in the bottom of the barrel, not being able to escape through *m*, must pass up through the valves, and rest upon the bucket *d*; when the bucket ascends, it carries before it this water and air, and as it rises, the space of the barrel above the bucket diminishes,

Machinery.

Manufac-
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and the rare vapour or air in it condenses by being pressed into less space, until at last it becomes equally dense with the atmospheric air, and then the water, following it, drives it through the valve *g* into the open air.

The ascent of the bucket *d* left a vacuum beneath it, as before, and this drew a portion of the air or vapour from the condenser into it, ready to be extracted by the next stroke. As soon as the bucket begins to return, the discharge valve *g* shuts, and prevents the atmospheric air from entering into the pump. By this we see that if the vapour in the condenser is so rare that the whole contents of the barrel of the pump will only make a few cubic inches, when reduced, to become equal to the pressure of the atmosphere, this small quantity will be effectually evacuated through the discharge valve *g*, because the water resting upon the bucket follows the air, and will chase every particle of it from the top of the pump, and then follow itself.

The air pump of Mr. Watt's engine requires to be of large dimensions, and the condenser is generally of the same size, by which means the rarefaction of any elastic vapour contained in the condenser will be equal to half at every stroke; that is, the air pump will extract half the quantity of the elastic vapour every time; because, supposing the vacuous space which the bucket of the pump leaves beneath it when it is drawn up to be equal to the capacity of the condenser, then the vapour in the condenser must expand itself to fill a double space, by which one half of it will enter into the pump, and be drawn out by the succeeding stroke, while the other half will remain in the condenser.

The cylinder of this engine is four feet diameter, and eight feet stroke, and the air pump two feet diameter and four feet stroke; thus their areas respectively are as one to four, and their capacities as one to eight. But it must not be considered that this large pump, full of air, is to be drawn out of the condenser at every stroke; for, as we have stated before, the vapour with which it is filled reduces itself to a small quantity before it comes to the density of the atmospheric air. At first we should be led to conclude that the pump affects the power of the engine as a deduction of as much power as the pressure of the air upon the surface of its bucket; but if we consider its construction, having a valve at *g* to keep off the pressure of the atmosphere, it is certain its bucket can have little weight upon the engine, until the bucket is near the highest limits of the stroke; and taking the sum of the resistance from the commencement of the stroke to its termination, it will be found to be very little in comparison with the power of the cylinder.

An air pump of one-eighth the capacity of the cylinder is sufficient to keep the condenser empty, when it is a single engine. If a smaller air pump were employed, it must be in action to lift out the air and water, for a greater portion of its stroke.

In fact, whatever the size of the air pump may be, it will occasion little more resistance to the engine than from the friction of its bucket, except during the time that it has actually opened the valve *g*, to discharge the air or water which it contains; before that period, the resistance is only that of compressing the vapour, an operation which begins at nothing, but increases by an ascending proportion reverse to that of the decrease of the pressure of the steam, when acting in the cylinder by expansion, as we have before explained.

In Mr. Watt's early engines the air pump and con-

densing cistern were placed at the outer end of the Machinery beam; and there are some reasons to prefer that mode of construction where the building will admit of it. In this case the pump bucket being drawn up by the descent of the piston, the engine requires a less counter weight than in the form just described, in which the air pump must be wholly worked by counterweight. Also, it is during the descent of the piston that the action of the air pump is most necessary; and it is possible that an engine, having the pump worked by the outer end of the beam, may make a better vacuum than when it is worked by the inner end, because there may be some, though a very slight, impulse given to the remaining air of the last stroke, by the rush of steam into the condenser at the instant the steam piston begins to descend, and the air pump to rise; for no sooner is the exhausting valve opened, than the steam rushes towards the condenser, and giving a momentary tendency to a plenum therein, may give a push to the air through the hanging valve, between the pump and the condenser; and hence it is reasonable to conclude, that more air will enter the pump by this means, than if it were left to its own expansion.

It is necessary that the parts appropriated to the condensation of steam should be kept as cold as possible, and those intended for the operation or passage of the steam as hot as possible; hence the air or discharging pump and condenser are placed in the cistern of cold water, which is kept constantly full by the cold water pump, and a little running away into the well to carry off the excess of heat; and if the injection valve is placed low in this cistern, it will take the water in the coldest state. The injection valve and cock are best seen in pl. xii. fig. 3.

As the condensing apparatus is immersed in water, to be kept cold, so the cylinder should, if possible, be immersed in steam, to be kept hot; for which purpose, Mr. Watt, from the first, used a casing or jacket round the cylinder, and also at the top and bottom: this was attended with very beneficial effects, although it enlarged the steam surface, and exposed the external jacket to a more rapid condensation than would have taken place from the surface of the cylinder itself. But to have the vacuum as perfect as possible, it is necessary that the cylinder be kept up to such a temperature as to prevent the least condensation of the steam upon the internal surface, either above or below the piston; because, if the sides of the cylinder were to be wet, as in the common atmospherical engine, the vacuum would be vitiated, as there would be occasioned by this wetness a moisture gradually forming to steam, which the outside casing prevents when filled with steam from the boiler, and the heat which escapes from the surface of the jacket does not injure the operation of the engine; but if it were possible to cover this outward case again with any sort of substance which would entirely prevent the transmission of the heat from the casing, it would supersede the use of the jacket altogether, and would apply with more advantage to the cylinder itself; but we do not know of any substance which will not admit this transmission more or less. Some of Messrs. Watt and Boulton's best engines we have seen surrounded by a case of polished copper, we believe outside of the jacket.

In small engines it is common to place the cylinder within the boiler, and it must then be kept fully as hot as the steam which enters it; but this is not practicable in a large engine, nor is it advisable in any case, because

the frequent repairs which the boiler requires must derange all parts of the engine.

When the jacket is used, a small copper pipe is conducted from the steam pipe to keep it full. As the jacket of a large cylinder must be exposed to be heated or cooled less than the metal cylinder to which it is attached, the unequal expansion might break the joints; to avoid this, the jacket is made in two halves put together in the middle of the length, without any other attachment than that of entering into each other for three or four inches, with a cup which is packed with hemp and tallow. The steam pipe has a similar joint which unites it to the box of the exhausting valve K, and will admit of drawing out a little without permitting the steam to escape.

(204.) *Double acting engine.*—Having in the preceding explanation of the single acting engine, entered into a minute description of the action of the air pump, condenser, and several other parts which are common also to the double acting engine, it will not be necessary again to recur to these particular points, but briefly to explain the general construction and principle of the engine. We select for this description an engine of Murray and Wood of twenty horse power; but it may be considered as a general description, the principal difference between one and another consisting in the manner of opening and shutting the valves, and some other minutiae. In this engine the working the valves is effected by eccentrics placed below the valve rods; in others by an eccentric working a lever connected with these rods and balanced by a large counterweight: in some cases the slides for opening and closing the valves is packed at the back, in others, the slide is kept up to the face by the mere pressure of the steam against the opening leading to the vacuum. This latter is the arrangement of Mr. Hague of Ratcliffe, and the action or pressure is said to be found much more uniform than with the packed piston. It is however impossible to attempt a description of all the different principles which have been introduced. We give the following, therefore, as a general illustration of the action of the double engine. Here (plate xiv.) is the representation of the engine. B is the cylinder inclosed in its steam jacket; C the pipe conducting the steam from the boiler to the steam case or valve tube D; E the eduction pipe leading to the condenser F; G is the air pump; H the cold water cistern; I the cold water pump; and K the hot water pump; the action of each of which are sufficiently shown in the drawing; L the piston rod connected with the parallel motion; S is the connecting rod between the beam Q and crank T; this gives rotation to the toothed wheel U, which, working in another wheel on the axle V, gives again rotation to the shaft V and fly wheel W; and other wheels on this shaft, or on the crank shaft, give motion to the Machinery intended to be worked by it. Sometimes the fly wheel is on the crank shaft, and by straps this fly wheel is made to work other fly wheels at some distance. This is the case in Woolwich Dock-yard, in the engine employed to work the large hammer and rolling mill. X Y Z are three bevelled wheels, the first of which is attached to the crank shaft, and, by means of the intermediate wheel and shaft Y, gives motion to the third, which by two eccentric rollers moves the valves. This is better seen in plate xii. fig. 4, which is an enlarged representation of this part, seen endwise, and the particular action of which has been already described in Art. 195.

The governor is worked by a band *b b* passing over a pulley on the crank shaft, and another on the vertical axis of the governor itself, which latter is also shown enlarged in the figure referred to above. To put the engine in action the fly wheel W must be turned till the crank T is in a horizontal direction, when the piston will be in the middle of the cylinder B, and the eccentric wheel be on the upper side of the shaft Z. The bar *w w* will also be raised together with the valves *v* and *p*, and the handle B being turned a passage will be opened for the steam to blow from the pipe C, and thus expel the atmospheric air, which previously filled the different parts of the engine. When this is effected, and the temperature of the engine is raised, the lever B must be turned to its original situation; the bar *v v*, together with its valves, will descend, and the steam will be shut off from the upper part of the cylinder, while at the same time the passage will be stopped between the under side of the piston and the condenser. The injection cock must now be opened, which will admit a small jet of cold water into the condenser, and a partial vacuum will be formed above the piston, while the steam is entering beneath with a pressure equal to that shown by the gauge above the atmosphere. The piston rod being thus made to descend in the cylinder, the opposite end of the beam will be depressed, and the rod S and crank T will also descend, and a rotary motion will be produced. The fly wheel also will have acquired a sufficient degree of momentum to carry the crank past the perpendicular, and the piston will have arrived at the top of the cylinder. The situation of the valves being reversed by the action of the eccentrics, a continuous motion is thus produced.

(205.) *High pressure engine.*—This engine was one amongst the earliest steam engines, at least in imagination, having been suggested by Leupold in 1720; it was also one of the principles of working which formed a part of Watt's patent, and was attempted by others, but was not brought into actual practice till 1802, by Trevithick. This is the more extraordinary as its principle of action is so much more simple than the condensing engine. In the latter a vacuum is produced, or partly produced, on one side the piston, and the steam acting on the other side, the piston is urged forward by the difference between the two; now in the high pressure engine the piston being opened to the atmosphere instead of to the condenser, is pressed on one side by the atmosphere, and on the other by the pressure of the steam. This, therefore, only requires the steam to be raised to a higher degree of elasticity, which being effected, all the apparatus of condenser, air pump, cold water pump, &c. are immediately dispensed with, and the engine assumes a very simple character. Trevithick's engine, however, was not of this simple kind, its entire figure and construction having been such as to fit it for the purpose of locomotion, which was the principal object of the inventor, and to him we owe the first demonstration that such object might be effected by the power of steam. Having, however, this specific object in view, we beg to refer the reader for a further description to the Chapter on the application of steam to locomotive engines.

Many high pressure engines resemble in all their exterior form the usual double acting vacuum engine, but as the beam is not so essential in an engine working by high pressure steam, as in the low pressure engine, this is very frequently dispensed with.

Manufac-
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Pl. xv.
Fig. 1 and 2,

Vibrating
engine.

Howard's
vapour
engine.

An engine of the latter kind is represented in plate xv. where fig. 1 is a front elevation, and fig. 2 a side elevation. The cylinder CC is supported upon cast-iron framing AA firmly bolted down to the beams BB. To its upper end are attached the cast-iron sides DDD, which serve to guide the piston rod of the cylinder in a truly vertical direction, by supporting two wrought-iron rods *aa*, which pass through an enlarged part of the cross head EE, which works the crank FF on the main shaft of the engine. The steam is conveyed by the pipe SS to the box CC containing a slide valve, which admits the steam to the top and bottom of the cylinder through flat pipes cast in its thickness. Motion is given to the slide by a heart-shaped crank on the main shaft, shown by the dotted lines at *d*, fig. 1, which works inside a rectangular piece of wrought iron, forming part of the vertical spindle *ff*, and conveys to it by its rotations a reciprocating motion, which by the horizontal lever *gg* is communicated to the slide rod. *kk* is the throttle valve, which, as in the common engines, is regulated by a governor C, put in motion by a system of bevelled wheels from the main shaft.

(206.) *Vibrating engine*.—This is an exceedingly simple construction, and, in cases where the power is not great, is very convenient. It may be worked either by high or low pressure steam, or by means of a vacuum, as described in a subsequent article. It was the original invention of Mr. Witty, but it has been more largely constructed by Mr. Hague, engineer, Ratcliffe, than by any other person. Some difference is found in the construction of this engine, but principally in the method of admitting the steam; and lately, Mr. J. Maudsley of Newington has taken out a patent for a method of admitting the steam very nearly in the same way as in the usual engine. The more common method is to suspend the cylinder on two strong, hollow, cylindrical trunnions, at its centre of gravity in proper bearings, and supported by two sides of a cast-iron frame; on each side of one of the supports two pipes, or openings are carried through the side of the frame, in either case opening at top into the bearing on which the engine swings; one of these pipes opens downwards into the atmosphere in the high pressure engine, or into the condenser or vacuum in the other cases, while another pipe is connected with the boiler. Two openings are formed in the axle on which the cylinder is supported, and which communicate with the top and bottom of the cylinder, whereby, when the engine is set to work, these openings or valves are alternately connected with the induction and eduction pipes, as the piston ascends or descends, this being made to work a crank which produces the required rotation. This description will here be sufficient, as an engine of this kind is represented in a figure, and its action more particularly illustrated under "Application of the steam engine to navigation."

(207.) *Howard's steam or vapour engine*.—The variety of forms which have been given to the steam engine within the last thirty years is so great that to attempt any thing like a description of them would require a large volume. Many of the combinations and arrangements are exceedingly ingenious, and possess perhaps some advantages for particular purposes; but few if any have acquired that degree of notoriety to justify us in entering upon a further description of them than we have already done. We are, however, disposed to make an exception in the present case. The object attempted in this engine is to dispense with the boiler, by producing

the steam only at each stroke of the engine. We have seen the engine at work at the King and Queen Iron Works at Rotherhithe, and to every appearance it was performing its duty remarkably well: it was afterwards examined by Mr. Kingston, the engineer in His Majesty's Dock-yard at Woolwich, and on his report one is now allowed by the Admiralty to be put for trial in the Comet steam packet. If it should be found successful on this large scale it will undoubtedly be a most important advantage in steam navigation; the room at present occupied by the boilers being a serious deduction from the space of the vessel. It is a low pressure engine, acting by condensation, and differs in no respect in form from Watt's double acting engine, but it is stated to require only half the fuel of the latter. The following is the inventor's own description. In the vapour engine, a high temperature acts upon such small quantity of liquid as will produce only a low comparative density, so that the rapidity of vaporization is not impeded by a corresponding pressure. This is effected as follows.

The heat from a coke fire is conveyed to the surface on which the vaporization is performed, through the medium of such quantity of mercury as will render the varying intensity of the fire, &c. sufficiently manageable: its temperature being indicated by a thermometer, which, when water is employed, should not be much lower than 400° Fahrenheit, but may be allowed to fluctuate between that and 500°, without perceptibly affecting the power of the engine. The surface exposed to the fire, in the engine of ten horses power now at work, is the bottom of a shallow wrought-iron pan, containing the mercury, and presenting to the fire seven square feet, or three-fourths of a square foot per horse power. It is placed beneath the working cylinder, which is twenty inches diameter. With alcohol a still less surface will suffice. Above the mercury is a very thin covering of iron, so contrived as to present about four times the fire surface, and is throughout in close contact with the mercury beneath. The vaporization is effected by dispersing upon the latter surface, at intervals, (say each stroke of the piston,) through a nozzle adapted to the purpose, the required small quantity of water, alcohol, or other liquid, previously heated to about its boiling point, which is instantly and completely vaporized. The quantity of liquid injected, on which the power of the engine is dependent, is regulated by the movement of a small valve, adjusted either by hand or by a governor. It is not necessarily presumed that any advantage would result by employing mercury, or other fluid medium, in the ordinary boilers or generators.

The fire is supplied by a blowing machine with air, which passes through a regulating valve, and is so admitted to the fuel as to act uniformly on it. A chamber surrounds the working cylinder into which the vapour passes, previously to its entering the latter by the induction valves. The heat from the fuel, that has not been absorbed by the mercury, passes, prior to reaching the flue, through a casing enclosing the chamber, by means of which the vapour within the latter is heated, say to about 400°: at the same time the pressure is in general only twenty or twenty-five pounds per inch, including that of the atmosphere. Thus, instead of the considerable loss of effect from condensation which takes place in the steam engine, an additional expansion is given to the vapour after its formation, to the extent of nearly one half; that is, one volume of steam at 212° become: one and a half at 450°.

Machinery

Manufac-
tures.

Machinery

In order to improve the process and save fuel, the vapour is worked expansively, for which it is well adapted; being cut off from the cylinder at about a fourth of the stroke, giving, for instance, an average pressure throughout the stroke of twelve pounds per inch, when the pressure for the fourth part is twenty pounds per inch. The quantity of coke consumed by the present engine, worked with water, is forty-five pounds per hour, or four and a half pounds per horse power; and it is expected that it may be further reduced.

The condensation is performed by *injection* in the following manner:—The condenser is a copper vessel, placed in a cistern constantly supplied with cold water, and receives the vapour or steam from the cylinder by an eduction pipe as usual: two pumps, worked by the engine, are connected with the bottom of the condenser, and a copper pipe proceeds from them, which, after many coils in the cistern, so as to expose a sufficient surface to the cold water, enters the condenser at the lower part, being furnished at its termination therein with a loaded valve. Such quantity of liquid is introduced into the condenser as will entirely fill the pipe and pumps, and enable the latter to act effectively. The pumps continually withdraw the warm liquid from the bottom of the condenser and pass it along the pipe, by which means the heat is abstracted from it, when, being injected through the valve amidst the vapour, (admitted into the condenser from the cylinder,) it instantly reduces it to the liquid state. No air being introduced, (as in the steam engine with the injection water,) a very small air pump is sufficient, being merely employed to exhaust it at starting, and what may enter by casual leakage. The condensation is fully as rapid and complete as in the best steam engine. A small pump conveys the liquid from the condenser to the valve before described, attached to the vaporizing apparatus. This process of condensation is equally applicable to the steam engine, with the important advantage of allowing the same water to be continually returned to the boiler.

(208.) *Method of conducting steam power to a distance from the engine.*—It is of course desirable to have the steam engine erected on the spot where its power is to be applied; but it happens frequently, that power for occasional purposes may be wanted at some distance from the spot on which the engine stands. Sometimes in mines, a certain power in the galleries to bring carriages up inclined planes, or even to stamp ores on some level where there is an adit of water, is very desirable, although it might be dangerous or inconvenient to have the steam engine in these places. In the occasional working of cranes and other Machines on the tops of buildings, on wharfs, and in a variety of other cases, it may be attended with great convenience to be able to apply the power of a steam engine situated at a distance in another part of the establishment; a principle of working which has been carried to a considerable extent by Mr. Hague, a very ingenious engineer, of Ratcliffe, to whom we have already frequently referred.

This is effected by having an air pump worked by the engine applied to a close vessel, so as to produce a vacuum or a rarefaction to a certain amount, and to have a pipe leading from this vessel to the point where the power is wanted; at this place a cylinder like that of a steam engine may be employed, the power which gives motion to its piston being the alternate opening of its top and bottom to the pressure of the atmosphere, while the other side of the piston is opened, by means

of the communicating pipe, with the vessel in which the rarefaction is produced; by this means a pressure equal to the difference between that of the atmosphere and that in the rarefied vessel, is the motive power, and may be employed in the same manner as that of the steam in the high pressure or low pressure engine. According to this principle of working, it is found best to have the rarefaction carried to about half the atmospheric pressure; and, consequently, the capacity of the air pump cylinder must be equal, or exceed double that of the working cylinder. This working cylinder is generally made to act on the vibrating principle, described Art. 206; and in the few cases the writer of this article has seen, the performance is very satisfactory, little or no power appearing to be lost by this mode of transmission: an object which it would perhaps be impossible to accomplish in any other way; besides, the great inconvenience which must attend any mode of connection by ropes or otherwise, would, in most cases, prevent a proprietor of works from availing himself of the spare power of a distant engine, whereas, in the way above described, no inconvenience of any kind is experienced. Mr. Hague has thus in one case carried the spare power of an engine to a distance of two miles, and in several instances the power of an engine at the pit's mouth of a mine has been conducted into one or more galleries. This mode of communicating power is also now generally employed in the processes of coining, as will be seen under that article.

(209.) *On the actual power of the steam engine.*—In several of the preceding articles it has been necessary to refer to the power of the steam engine, the consumption of fuel, &c., but we have generally made merely an estimate, and have not hitherto entered minutely into this question. It has been stated, that the most common unit of comparison is the horse power, and each horse power is estimated by the number of pounds raised in a minute to the height of one foot; Watt assuming this number to be 33,000 pounds. This of course includes time as an element; but another method of estimation, also proposed by Watt, was, to estimate the power, or, as it is called, the efficiency of an engine by the number of pounds which may be raised one foot by the consumption of a bushel of coals. Here, however, time is not an element, and is not therefore apparently so proper a form of comparison as the former; we shall, however, examine the action according to both forms.

When Messrs. Boulton and Watt had brought their engine to perfection, they charged their profits in proportion to the saving of fuel effected by it, as compared with a common engine of the same power, and burning the same coals; one-third of these savings having been paid them annually, or the whole amount, adequately adjusted for prompt payment, paid in one sum. This comparison, however, was not to be made on the recent engines of Smeaton's construction, he having already effected considerable saving, as has been shown in our Historical Chapter. Smeaton had undoubtedly reduced the consumption of coals about a half or a third; and Watt had again reduced the consumption to about one half of that used in Mr. Smeaton's best form; so that, upon the whole, it may be said that Watt saved in the comparisons by which he was guided, about three-fourths of the fuel originally consumed, and one-third of this saving he enjoyed the advantage of during his exclusive right granted by the original patent and its Parliamentary extension.

Boulton and
Watt's first
engines.

Manufac-
tures.

The power which was assigned to his engine in the earliest constructed ones, was, that they should raise 500,000 pounds of water one foot high, by the consumption of one hundred-weight, or 112 pounds of coals, which is equivalent to raising twenty-four millions and a half pounds one foot high by the consumption of one bushel of coals. This, however, seems to have been an over-rated statement; or, at least, it belonged only to the most perfectly constructed engine, and when in its best state for working; for, by an experiment of Mr. Smeaton, who was desirous to promote by all means the introduction of the condensing engine, he obtained a result of only nineteen millions. This experiment was made on an engine on the Birmingham canal, for returning into the reservoir the water let down by the passage of boats through the locks. The working cylinder was 20 inches, and the pump also 20 inches, lifting 27 feet, at the rate of 11 strokes per minute, each stroke being 5 feet 9 inches.

Here $20^2 \times .7854 = 314$ square inches area, or $\frac{314}{144}$

square feet raised one foot high per minute;

$$\frac{314}{144} \times 5\frac{3}{4} \times 11 = 138 \text{ feet}$$

raised 27 feet per minute.

Hence $138 \times 27 \times 60 \times 62\frac{1}{2}$ pounds = 13,961,805 pounds raised one foot high per hour.

The coals (which were the Wednesbury) consumed in an hour, were 65 pounds; and hence

$$65 : 88 :: 13,961,805 : 18,902,136 \text{ pounds}$$

raised a foot high, which, calling it nineteen millions, is considerably below the estimate above stated. And yet this was probably a favourable case; for it appeared in 1811, that the general medium of the Cornwall engines, which were principally of the construction of Boulton and Watt, did not exceed an effect of more than thirteen millions and a half raised one foot by a bushel of coals. Much of this deficiency was, however, no doubt due to the inattention of the engineer; for about that time comparisons being made between the different engines, and their working powers regularly registered and reported, the engineers felt themselves as it were responsible for the performance of those under their immediate charge; and the consequence has been, that from a medium of thirteen millions and a half, they have been gradually increasing in power, till, in one instance, an engine was made to perform for several successive days the amount of one hundred and three million pounds raised a foot high: it did not, however, continue working at this rate, but settled down steadily to eighty millions, which it still continues to perform. This is quite on the maximum side at present, but almost daily improvements in the economy of working the engines is going on in Cornwall, so that it is difficult to foresee to what length it may ultimately be carried. The gradual annual improvement will be seen by the following short Table, stating the number of engines in several successive years, and their average duty actually performed.

	No. of Engines.	Average Duty.
In 1811	—	13.5 millions.
1823	55	26.9
1824	57	28.
1825	62	28.97
1826	63	28.36
1827	62	31.9
1828	64	34.85

Cornwall
single act-
ing engines.

Further particulars relative to these engines will be given under the *Application of Steam Engine to Mining*. It will be sufficient here only to remark, that they are mostly single acting, and being principally employed in pumping or raising ores, they may be perhaps worked more economically than those used to produce rotation, and to drive Machinery, whose diameters, velocities, pressure per square inch, and other minutiae, are more restricted. Generally in the smaller engine of the latter kind, the capacities and length of stroke are so arranged that the surplus pressure (after deducting the friction and resistance of air, pump, piston, &c.) is such, that this pressure on the whole piston amounts to a hundred and fifty pounds multiplied by the number of horse power, and the speed two hundred and twenty feet per minute; but in the larger engines, the pressure is a hundred and sixty-five, multiplied by the nominal horse power, and the speed about two hundred feet per minute. Some variation, however, in these respects, is made by different makers; but the following Table shows the general proportions of what are esteemed the best land engines. In steam vessel engines the strokes are generally shorter, but the pressure, diameter, and speed are the same, the diminished length of stroke being compensated for by a greater number being made in a given time.

The surplus pressure on the piston cannot be correctly ascertained in any way, except by knowing the actual duty the engine is performing; but the real pressure is easily determined, being equal to the difference of the pressure on the steam and vacuum side of the piston. The pressure on the steam side is, of course, equal to that shown by the steam gauge plus the atmosphere, and that on the condenser side is equal to the difference between the vacuum gauge and the barometer.

Thus, if the steam gauge show 6 inches,

the pressure on the steam side is $6 + 30 = 36$ inches

And if the condenser gauge show 28, the

pressure is $30 - 28 = 2$ inches

Difference 34 inches

Or 17 pounds per inch;

and about one half of this, or rather more, is generally supposed to be absorbed by the air pump and friction of the engine, leaving a surplus pressure of from seven pounds and a half to eight pounds and a half effective; the former in the smaller, and the latter in the larger engines.

The reader will see that as, in the above calculation, the atmosphere enters equally on both sides, and the difference is then taken, the result is the same as adding together the amount shown by the two gauges; that is, the actual pressure in the above case is equal to $6 + 28 = 34$ inches, or seventeen pounds per square inch. And this is the general language of engineers, who, as we said above, afterwards consider the half of this to be the effective pressure; but as the smaller engines have proportionally more friction than the larger, the former are commonly considered to average about seven pounds and a half, and the latter eight pounds and a half. Some, however, consider only half the pressure shown by the condenser gauge to be absorbed, as we have before stated, but we believe few engines arrive at this degree of perfection.

Machinery.

TABLE, showing the Dimensions, Velocities, Pressures, and Consumption of Coals per Horse Power per Hour, Machinery for Engines of different nominal Powers, both Single and Double acting.

Nominal Horse Power		Dimensions of Pistons.			Load on the Piston.		Velocity of the Piston, Length of Stroke, &c.				Weight raised 1 foot high in a minute.		Consumption of Coals per Hour.			
Double acting.	Single acting.	Diameter in inches.	Area in square inches.	Number of square inches for each Horse power.	Pressure per square inch.	Load on Piston.	Length of Stroke.	Number of Strokes per minute.	Velocity Double acting.	Velocity Single acting.	Cubic feet of Water.	Pounds Avoirdupois.	Double acting.		Single acting.	
													Pounds per Horse power.	Total.	Pounds for each Horse power.	Total.
1	1	6.0	28	28.0	7.	.199	1	50	166	83	528	33,000	20.7	20	10	10
2	1	8.3	54	27.4	7.2	.392	2	42	168	84	1,056	66,000	15.6	22	6.7	13
4	2	11.6	106	26.5	7.3	.777	2	34	170	85	2,012	132,000	13.8	55	6.9	27
6	3	13.9	152	25.4	7.0	1.070	3	31	185	92	3,168	198,000	12.2	73	6.1	36
8	4	15.9	199	24.9	6.9	1.389	3	27	190	95	4,224	264,000	10.5	84	5.2	42
10	5	17.7	245	24.5	7.	1.718	4	24	192	96	5,280	330,000	10.0	100	5.3	53
12	6	19.2	288	24.0	7.1	2.062	4	24	192	96	5,336	396,000	9.8	117	4.8	58
14	7	20.6	332	23.7	7.1	2.357	4	22	196	98	7,392	462,000	9.0	126	4.5	63
16	8	21.75	373	23.3	7.1	2.666	4	22	198	99	8,448	528,000	8.7	140	4.4	70
18	9	23.0	412	22.9	7.2	3.000	4	22	198	99	9,502	594,000	8.5	153	4.2	76
20	10	24.0	452	22.6	7.3	3.300	5	20	200	100	10,560	660,000	8.3	166	4.1	83
22	11	25.1	493	22.4	7.35	3.630	5	20	200	100	11,616	726,000	8.0	176	4.0	88
24	12	26.1	532	22.2	7.40	3.960	5	18	200	100	12,672	792,000	7.8	187	3.8	93
26	13	26.9	569	21.6	7.5	4.290	5	18	200	100	13,728	858,000	7.6	197	3.7	98
28	14	27.3	605	21.9	7.6	4.620	5	18	200	100	14,784	924,000	7.4	207	3.6	103
30	15	28.6	645	21.5	7.6	4.897	6	17	204	102	15,840	999,000	7.2	216	3.6	108
32	16	29.5	682	21.3	7.6	5.176	6	17	204	102	16,896	1,056,000	7.1	227	3.5	113
34	17	30.3	721	21.2	7.5	5.500	6	17	204	102	17,952	1,122,000	7.0	238	3.5	119
36	18	31.0	756	21.0	7.7	5.823	6	17	204	102	19,008	1,188,000	6.9	249	3.5	124
38	19	31.8	805	20.9	7.6	6.028	6	16	208	104	20,064	1,254,000	6.8	258	3.4	129
40	20	32.6	832	20.8	7.6	6.346	6	16	208	104	21,120	1,320,000	6.7	268	3.3	134
42	21	33.3	869	20.7	7.65	6.663	6	16	208	104	22,176	1,386,000	6.6	279	3.3	139
44	22	34	906	20.6	7.7	6.980	6	16	208	104	23,232	1,452,000	6.5	286	3.2	143
46	23	34.7	943	20.5	7.7	7.298	6	16	208	104	24,288	1,518,000	6.4	294	3.2	147
48	24	35.3	979	20.4	7.7	7.543	7	15	210	105	25,344	1,584,000	6.3	302	3.1	151
50	25	36	1020	20.4	7.7	7.857	7	15	210	105	26,400	1,650,000	6.2	310	3.1	155
52	26	36.6	1055	20.3	7.75	8.171	7	15	210	105	27,456	1,716,000	6.1	317	3.0	158
54	27	37.3	1092	20.3	7.77	8.485	7	15	210	105	28,512	1,782,000	6.1	329	3.0	164
56	28	38	1136	20.3	7.79	8.800	7	15	210	105	29,568	1,848,000	6.0	336	3.0	168
58	29	38.8	1172	20.2	7.79	9.114	7	14	210	105	30,624	1,914,000	6.0	348	3.0	174
60	30	39.2	1206	20.1	7.8	9.428	7	14	210	105	31,680	1,980,000	5.9	354	3.0	177
62	31	39.8	1246	20.1	7.8	9.742	7	14	210	105	32,736	2,046,000	5.9	366	2.9	183
64	32	40.4	1280	20.0	7.85	10.057	7	14	210	105	33,792	2,112,000	5.9	378	2.9	189
66	33	41.0	1320	20.0	7.9	10.371	7	14	210	105	34,848	2,178,000	5.9	384	2.9	191
68	34	41.6	1360	20.0	7.9	10.686	7	14	210	105	35,904	2,244,000	5.9	394	2.9	197
70	35	42	1386	19.9	8.0	11.106	8	13	208	104	36,960	2,316,000	5.8	406	2.9	203
72	36	42.7	1433	19.9	8.0	11.423	8	13	208	104	38,016	2,376,000	5.7	410	2.8	205
74	37	43.3	1472	19.9	8.0	11.740	8	13	208	104	39,072	2,442,000	5.7	422	2.8	211
76	38	43.7	1505	19.8	8.0	12.058	8	13	208	104	40,128	2,508,000	5.7	433	2.9	216
78	39	44.4	1544	19.8	8.0	12.375	8	13	208	104	41,184	2,574,000	5.6	437	2.8	218
80	40	45	1590	19.8	8.0	12.692	8	13	208	104	42,240	2,604,000	5.6	448	2.8	224
85	42	46.2	1674	19.7	8.2	13.750	8	12	204	102	44,880	2,805,000	5.6	476	2.8	238
90	45	47.5	1773	19.7	8.2	14.558	8	12	204	102	47,520	2,970,000	5.6	504	2.8	252
95	47	48.7	1862	19.6	8.2	15.367	8	12	204	102	50,160	3,125,000	5.5	522	2.8	261
100	50	50	1963	19.6	8.2	16.176	8	12	204	102	52,800	3,300,000	5.5	555	2.8	277
105	52	51	2043	19.5	8.2	16.995	9	11	198	99	55,440	3,665,000	5.5	577	2.7	288
110	55	52.2	2145	19.5	8.5	18.333	9	11	198	99	58,080	3,630,000	5.5	605	2.8	302
115	57	53.4	2240	19.5	8.5	19.166	9	11	198	99	60,720	3,795,000	5.5	632	2.7	316
120	60	54.7	2340	19.5	8.5	20.000	9	11	198	99	63,360	3,960,000	5.5	660	2.7	330
126	63	56	2463	19.5	8.5	21.000	9	11	198	99	66,528	4,158,000	5.5	693	2.7	346
132	66	57	2552	19.4	8.5	22.000	9	11	198	99	69,696	4,356,000	5.5	726	2.7	363
136	68	58	2642	19.4	8.6	22.666	9	10	197	99	71,808	4,488,000	5.5	748	2.7	374
140	70	59	2734	19.4	8.6	23.503	9	10	196	99	72,920	4,620,000	5.5	770	2.7	385
145	72	60	2827	19.4	8.6	24.413	9	10	196	98	76,560	4,785,000	5.5	797	2.7	398
151	75	61	2922	19.3	8.6	25.426	9.6	10	196	98	79,728	4,985,000	5.5	830	2.7	415
156	78	62	3019	19.3	8.7	26.265	9.6	10	196	98	82,368	5,148,000	5.5	858	2.7	429
161	80	63	3117	19.3	8.7	27.246	9.6	10	195	97	85,008	5,313,000	5.5	885	2.7	442
166	83	64	3217	19.3	8.7	28.092	9.6	10	195	97	87,648	5,478,000	5.5	913	2.7	456
172	86	65	3318	19.2	8.8	29.258	9.6	9	194	97	90,814	5,676,000	5.5	946	2.7	473
178	89	66	3421	19.2	8.8	30.435	10.	9	193	96	93,984	5,874,000	5.5	979	2.7	489
189	94	68	3632	19.2	8.9	32.484	10.	9	192	96	99,792	6,237,000	5.5	1039	2.7	519
200	100	70	3848	19.2	8.9	34.555	10.	9	191	95	105,600	6,600,000	5.5	1100	2.7	550
212	106	72	4071	19.2	9.0	36.821	10.	9	190	95	111,936	6,996,000	5.5	1166	2.7	583

Manufac-
tures.

Application of the Steam Engine to Mining.

(210.) We propose under this head, not merely to confine our description to the working of the steam engine for the purpose of raising water or minerals, the stamping of ores, &c., but to take also a general view of the history of mining, both of metals and coals, to which mineral productions Great Britain is so highly indebted for her elevated rank amongst nations; and which sources of wealth and power must ever have remained buried far below her surface, but for the invention and subsequent improvements of the steam engine.

To the difficulty of working the deeper mines, there can be no doubt we owe, if not the invention of the steam engine, at least that spirit of encouragement which brought it to perfection; and the engine has in return furnished the means of working mines which, but for its aid, must ever have remained unexplored. It will, therefore, it is presumed, not be considered out of place, while we are pointing out the extraordinary assistance which our mining districts have derived from this engine, if we take a concise view of the art of mining, and the produce derived from it prior to this invention, as the reader will thereby be the better able to appreciate the importance of its application in these operations.

History of
mining for
tin and
copper.

(211.) *History of mining for tin and copper.*—Of all the mineral productions of England, there seems no doubt that tin was the first known; this metal, according to most historians, forming an article of commerce in very ancient times with the Phœnicians, long before the invasion of this Country by the Romans. Tin works were certainly carried on before the use of iron was known, and probably before it was known to possess metallic properties. Many tools of oak, obviously used in mining, are occasionally found in old works, which tradition amongst the miners ascribes to the Saxons and Danes, but which were, in all probability, the rude instruments of the ancient Britons. Mining at this time must have been of a very simple character. Without the means of raising either ores or water, except by manual labour, and without iron to separate the blocks in which it might be discovered, it is pretty obvious, that at this time but little penetration could be effected below the surface; consequently, those metals were first worked which presented themselves nearest to the surface, and of this kind is tin. It is indeed probable, that nearly all the tin procured in former Ages was by means of stream works, in bottoms or low grounds, where fragments of the ore, washed from the *lodes* in the neighbouring hills, subsided, and were separated from the earth in a granular form by washing. This, of course, was obtained without any subterraneous work; and in such situations as these, probably, metals were first discovered, mixed merely with the upper soil, or lodging in the clefts of rocks: thus gold is found in Africa, in America, and other Countries. The tracing the ore into the earth itself, would almost follow as a necessary result, as soon as the surface failed of yielding a sufficient supply; and at this point the art of mining commenced, and the difficulties of the operation began to be experienced. At what time this took place, it is of course impossible to say, or, confining our remarks only to this Country, at what part, but most likely, from all records, in Cornwall and Devon. The difficulty which must have attended the keeping a mine, sunk to some depth, free from water by manual labour only, could not but prevent men, before the application of Machinery, from proceeding far

below the surface of the earth; and yet there are examples of old works which have been carried to a great depth; but these, though now old, were probably, indeed certainly, long subsequent to the early periods above referred to; and after iron, and the means of applying the powers of horses to mills or windlasses, had become known.

Many rocks are so hard as to yield with difficulty to manual effort; at least in such a degree as to render the operation profitable. As far as the process could be conducted, hammers and wedges were most probably employed for splitting the rocks, as they are still in ground that will yield to them, the pick or instrument for cleaving the ground being furnished with a head for driving the wedges, called by the Cornish miners *gads*. These instruments are sometimes found in old works, and their figure, it is said, bears strong testimony of their antiquity. Wedges of dry wood were also very ingeniously made use of, by driving them into the clefts and then wetting them, so as to cause them to swell and force the ground asunder. Fire also was employed to produce this effect; but it was only after the discovery of gunpowder that the miner was possessed of the power of separating into fragments the hardest blocks. This agent so far exceeded any other before made use of for such purpose, that its discovery and application to works of this kind form a grand epoch in the history of mining. This, it appears, took place in Hungary or Germany, about the year 1620, and was first introduced into England at the copper mine at Ecton, in Staffordshire, by German miners, brought over by Prince Rupert; but it was not in use in Somersetshire till 1684, after which, probably, the Cornish miners became acquainted with it. This discovery of gunpowder greatly facilitated mining operations, and hydraulic machines were constructed in situations where they could be fed by streams for raising water and the ores; and water wheels are still had recourse to where they can be worked conveniently with the same object, as well as for stamping and other processes; but it was the discovery of the steam engine which crowned all previous Arts, and gave a dominion to the miner he could never without it have dared to expect.

To recur again to the earlier period of mining in England, it appears that after the Romans left this Country, and it fell under the sway of the Normans, that the working of the mines was a good deal neglected; at any rate they seem to have been unprofitable, and to have been principally in the hands of the Jews, but began again to revive in the reign of Richard II. Edward I., however, having banished this unfortunate race, mining was again neglected, till Edmund, the eldest son of this Monarch, made some important alterations in the regulations of the tin works of Cornwall by a Charter, which was confirmed by Edward in the latter part of his reign. Indeed, it is from this time that the peculiar laws and privileges relating to the Stannaries are chiefly to be dated. Mining infringed in some instances on property, and caused disputes, besides requiring indulgences not general; and thus causes arose not cognizable by the common law. In this way a peculiar code, springing from custom, took its rise; and though this in some measure existed before, yet it was not till this period that it was confirmed by Royal Charter, and enforced by subsequent Acts of Parliament. It was by this Charter that the bounding land to the purpose of tanners working on it, the duties to the Earl of Cornwall, and the coinage of tin, or stamping with the Earl's

Machinery

Manufac-
tures.

seal, were first established. Before the reign of Edward I. tanners worked in the Earl's land only, paying him a fifteenth part of what they got, and they were not at all permitted to dig in sanctuary ground, churches, mills, houses, gardens, and so on; and, if in working under, they chanced to subvert any house, or to damage a high way, they were obliged to make it good. When it became an object to search throughout any place or person's lands, a Court also to determine cases relating to the tin works became necessary; and this adjudging under authority of, and according to the code of laws before mentioned, was first established by Edward I., and is called the Stannary Court.

In Cornwall and Devon two different systems of Stannary laws now exist: those in Cornwall have been from time to time amended and corrected; but in Devon, where mining has for a long while slumbered, the laws continue in their original crude state.

The Duke of Cornwall had Royal jurisdiction; and when the Duchy came into the hands of the Crown, which happened in the reign of Edward III., he made his eldest son, the Black Prince, the Duke, and appointed the Dukedom, with the revenue arising from it, to the sons and heirs apparent of the Crown, though no son of the King can be Duke of Cornwall but the first-born, even though heir-apparent.

The Stannary laws were explained and confirmed with some alterations at different times, till Arthur, eldest son of Henry VII., made certain constitutions relating to the Stannaries, which the tanners refused to observe; the King, after Prince Arthur's death, seized the Charter as forfeited, but granted a new one with fresh privileges, appointing all new laws relating to the tanners to be made by a Parliament of their own body; and upon this footing the Stannaries remain.

Great powers have been at times assumed by this jurisdiction: it has even taken upon it the trial for felony in the case of a tanner; in general, however, the cases where its authority interferes, are in disputes concerning tin-works, or between tanners; it provides a supply of water to a tin-work, giving a power to conduct it through any lands for that purpose.

Copper, of which so much is now sent from this part of the country, was not an object attended to till a comparatively late date by the Cornish miners; even in tin mines, which as they deepened produced copper, as is often the case, and where they needed to raise this ore, it was thrown by as of no value, going by the name of *poder*. Those who lived in later and more enlightened times reaped the profits left to them by the ignorance of their forefathers; and this proves of what consequence it is to determine, if possible, the

value of all the substances passing under the miner's observation.

Copper, however, was probably worked at a remote period in Wales, at Parys mountain, which, indeed, is supposed to derive its name from the Celtic word *praas*, brass or precious metal; and this would offer a proof of its having been worked by the ancient Britons. It was not, however, attended to, or at least not well understood in England till the reign of Queen Elizabeth, who paid great attention to the mines of the Kingdom, and, by granting great privileges to Daniel Haughsetter, Christopher Schutz, and other Germans whom she invited into England, commenced and established the highly valuable and important business of finding and purifying this useful metal. To these foreigners, too, is owing the flourishing state of our brass manufactories. In this reign Parys mine was granted to patentees, but was not worked, at least to any advantage, for a century and a half.

The copper mines of Cornwall are now works of great magnitude, many of them are sunk to amazing depths, some exceeding two hundred and forty fathoms, and are kept working at a vast expense. The quantity of materials constantly used forms an extensive commerce, which, together with the mines themselves, give employment to a very extended population.

We cannot enter into a minute statement of the several particulars of the different mines in this County, and much less of the general mines of England, but the continued and progressive annual product of the several mines, according to the best authentic returns, will occupy but small space, and be interesting to the reader, as it will be also to see the immense amount of steam power employed in the mines of Cornwall only. We have not the means of making a similar statement relative to the other mines of England, but assuming it proportional to their product, we shall find that the steam power employed in Great Britain for mining only, exclusive of iron and coal mines, amounts to the labour of one hundred thousand horses, or to that of five hundred thousand men; it is also interesting to observe how greatly the power of the engines individually have been progressively improving within the last twenty years. The reader will see by referring to the Chapter on the steam engine, that what is in the following Table denoted average duty, is the number of pounds raised a foot high by the consumption of one bushel of coals - and it will be seen (Art. 209 and 215.) that this average duty of the best engine in 1813 was only 26,460,000, with a mean average of 19,456,000, whereas in 1828 it amounted to 76,763,000, with a mean average of 34,850,000, and has more recently exceeded 80,000,000 in the best engines.

Machinery

Manufactures.

Annual product of the Cornwall mines.

(212.) *Account of the Copper produced from the Mines of Cornwall from the Year 1798 to June 1828. Showing the Quantity of Ore, of Metal or fine Copper, the Value of the Ore in Money, the average per Centage or Produce, and the average Standard, or Miner's Price of fine Copper, made up to the End of June for each Year.*

Machinery.

Years.	Tons of Ore.	Tons of Metal or fine Copper.				Value of the Ores.			Produce of Ores per Cent.	Average Standard.		
	Tons.	Tons.	cwts.	qrs.	lbs.	£.	s.	d.		£.	s.	d.
1799	51,273	9,423	5	3	27	469,664	8	0	9 $\frac{5}{8}$	121	8	0
1800	55,981	5,187	0	3	7	550,925	1	0	9 $\frac{1}{4}$	133	3	6
1801	56,611	5,267	18	3	10	476,313	1	0	9 $\frac{1}{2}$	117	5	0
1802	53,937	5,228	15	3	5	445,094	4	0	9 $\frac{5}{8}$	110	18	0
1803	60,566	5,615	16	0	21	533,910	16	0	9 $\frac{1}{4}$	122	0	0
1804	64,637	5,374	18	1	20	570,840	11	0	8 $\frac{3}{8}$	136	5	0
1805	78,452	6,234	5	0	6	862,410	16	0	7 $\frac{7}{8}$	169	16	0
1806	79,269	6,863	10	2	13	730,845	6	6	8 $\frac{3}{8}$	138	5	0
1807	71,694	6,716	12	1	26	609,002	13	0	9 $\frac{3}{8}$	120	0	0
1808	67,867	6,795	13	2	25	495,303	1	6	10	100	7	0
1809	76,245	6,821	13	1	19	770,028	15	6	8 $\frac{7}{8}$	143	12	0
1810	66,048	5,682	19	1	27	570,035	8	0	8 $\frac{1}{2}$	132	5	0
1811	66,786	6,141	13	3	7	556,723	19	0	9 $\frac{1}{8}$	120	12	0
1812	71,547	6,720	7	2	4	549,665	6	6	9 $\frac{3}{8}$	111	0	0
1813	74,047	6,918	3	0	6	594,345	10	0	9 $\frac{1}{4}$	115	7	0
1814	74,322	6,369	13	3	7	627,501	10	0	8 $\frac{1}{2}$	130	12	0
1815	78,483	6,525	6	3	25	552,813	8	6	8 $\frac{1}{4}$	117	16	0
1816	77,334	6,697	4	0	17	447,959	17	0	8 $\frac{3}{8}$	98	13	0
1817	76,701	6,498	2	0	16	494,010	12	6	8 $\frac{1}{2}$	108	10	0
1818	86,174	6,849	7	1	1	686,005	4	6	7 $\frac{7}{8}$	134	15	0
1819	88,736	6,804	2	2	7	623,595	4	6	7 $\frac{5}{8}$	127	10	0
1820	91,473	7,508	0	3	26	602,441	12	0	8 $\frac{1}{8}$	113	15	0
1821	98,426	8,514	19	2	12	605,968	19	6	8 $\frac{5}{8}$	103	0	0
1822	104,523	9,140	8	3	20	663,085	13	6	8 $\frac{3}{4}$	104	0	0
1823	95,750	7,927	17	2	7	608,033	1	0	8 $\frac{1}{4}$	109	18	0
1824	99,700	7,823	15	1	10	587,178	3	6	7 $\frac{7}{8}$	110	0	0
1825	107,454	8,226	3	0	21	726,353	12	0	7 $\frac{5}{8}$	124	4	0
1826	117,308	9,026	12	3	15	788,971	15	6	7 $\frac{5}{8}$	123	3	0
1827	126,710	10,311	14	3	15	745,178	1	0	8 $\frac{1}{8}$	106	1	0
1828	130,366	9,921	1	2	11	756,174	16	0	7 $\frac{5}{8}$	112	7	0

(213.) *Amount of the Produce of each of the Copper Mines of Cornwall in Ore, Copper, and Money, for the Year ending June 30, 1828.—The Fractional Parts of Tons are omitted.*

Names of Mines.	Tons of Ore.	Tons of fine Copper.	Value of the Ores.	Names of Mines.	Tons of Ore.	Tons of fine Copper.	Value of the Ores.
Consolidated Mines.....	13,879	1,265	101,008	Wheal Talgus	1,290	153	12,979
Penstruthal	10,295	650	48,645	Cook's Kitchen	2,490	139	10,276
Dolcoath	9,012	631	49,070	Stay Park.....	1,898	118	9,095
East Crinnis	8,057	618	44,180	United Mines.....	1,384	112	8,545
Lanescot	7,500	603	41,248	Wheal Hope.	952	99	8,107
Poldice and Wheal Unity	4,516	381	30,458	Great St. George.....	1,684	97	6,915
Fowey Consols	4,216	340	23,494	Carzise	952	90	7,243
Wheal Buller and Beauchamps	5,197	304	22,444	Crinnis Consols	1,326	89	6,380
Pembroke	4,209	277	20,064	North Downs.....	970	81	6,185
Wheal Montague and Harmony	2,348	273	22,404	Wheal Chance.....	852	71	5,529
Binner Downs.....	3,986	265	20,486	Wheal Rodney	1,150	70	5,257
Herland.....	2,151	229	18,655	Levant	581	58	4,496
Wheal Damsel	2,186	215	17,365	Wheal Charlotte	886	57	4,119
Wheal Bissy.....	3,881	214	15,470	United Hills.....	945	53	3,835
North Roskear.....	3,285	213	16,226	Wheal Trannack	763	52	3,810
Wheal Gorland	2,870	204	15,666	Botallack	426	48	3,729
Wheal Towan	3,337	203	15,258	Wheal Leisure.....	377	46	3,736
Wheal Trenwith	1,427	195	16,190	Wheal Fortune.....	549	44	3,530
Tingtang	2,463	194	15,070	Wheal Cock.....	404	40	3,034
Wheal Maiden and Carbarrack	2,519	177	13,745	Wheal Mary (West).....	462	32	2,481
Wheal Chance Consols	1,955	176	13,559	Condorow	452	31	2,347
Treasavean.....	1,714	159	12,699	Cardrew.....	396	29	2,209
Wheal Caroline	2,400	156	11,851	Wheal Charles.....	467	28	2,014

Manufac-
tures.

	Tons of Ore.	Tons of fine Copper.	Value of the Ores.
South Towan	499	27	1,900
Wheal Raven	337	26	1,997
Wheal Bassett	281	25	1,911
Wheal Mary St. Neot's	357	24	1,856
Wheal Speedwell	311	17	1,249
Wheal Spinstar	203	16	1,289
North Sealhole	255	15	1,112
Unanimity	237	13	802
Wheal Penwith	66	10	826
Mines under ten tons	1,420	94	6,635
Total	130,366	9,921	756,174

(214.) *Account of the Produce of the Copper Mines of Ireland, Devonshire, Cumberland, and Staffordshire, in Ore, Copper, and Money, in the Year ending 30th June, 1828.*

Ireland.

	Tons of Copper Ore.	Tons of Fine Copper.	Value of the Ores.
Allihies	2,524	290	25,044
Cronbane	1,482	107	9,033
Wicklow	2,164	87	6,631
Tigrony	1,076	85	7,216
Ross Island	591	76	6,541
Audley	388	45	3,855
Sundry small parcels	353	24	2,003
	5,878	714	60,323

Wales.

Angleseaabout	730		
Llandidno	766	117	10,138
Dolfrwynog	253	30	2,410
Llanberris	245	25	2,132
Simnia Dyllan	106	12	1,038
Sundry small parcels	233	19	1,648
	1,603	203	17,366

Devonshire.

Wheal Friendship	2,841	354	29,100
Virtuous Lady	533	44	3,410
Wheal Crebor	164	10	730
Sundry small parcels	344	22	1,625
	3,882	430	34,865

Cumberland.

Leehousewell	168	29	2,662
Conistone	172	21	1,756
Stoweragg	64	10	922
	404	60	5,340

Staffordshire.

Auxonabout	20		
Ectonabout	10		
	30		

Quantity of Copper produced in Great Britain and Ireland in the Year ending 30th June, 1828

	Tons.
Cornwall	9,921
Devonshire	430
Staffordshireabout	30
Cumberland	60
Angleseaabout	730
Other parts of Wales	203
Ireland	714
	12,088

Account of Tin raised in Cornwall and Devon.

1822	18,732 blocks, or 3,137 tons.
1823	24,077 4,031
1824	28,602 4,819
1825	24,902 4,170
1826	26,299 4,406
1827	31,744 5,316

The produce of the first nine months of the year 1828 was 21,749 blocks, or 3,642 tons.

(215.) *Account of the Quantity of Lead raised from the Mines of Great Britain.*

As no regular accounts can be obtained of the produce of this metal from mines dispersed in so many districts, the quantity can only be estimated, and the following are the results of a careful inquiry amongst those who are best acquainted with the subject. The produce of each district in which mines are worked is stated upon a comparison of various authorities, and exhibits a considerable increase when compared with a similar estimate made about five years since, when the whole appeared to be about 36,000 tons.

	Tons of Pig Lead.
1828. Mines of Weardale, Alstone Moor, Teasdale, Derwent, &c., in Cumberland, Durham, and Northumberland	22,000
Swaledale, Grassington, Pateley Bridge, &c. Yorkshire	4,700
Derbyshire	3,000
Shropshire	1,800
Devonshire and Cornwall	2,000
	33,500
Wales, principally from Flintshire and Denbighshire	12,090
Scotland	1,000
Ireland, Isle of Man, &c.	500
Total produce of Great Britain	47,000

Estimate of the Quantities of Copper, Tin, and Lead used for Home Consumption or manufactured in Great Britain, upon the Return of 1827, the latest Period to which the Accounts of Reports have been made up.

	Tons.
Produce of the mines	12,635
Foreign copper imported	575
	13,210
British and foreign copper exported	7,875
Remains for home consumption	5,335

Manufactures.

Tin.

Produce of the mines	Tons.
Foreign tin imported	5,316
	100
	5,206
Tin exported	2,620
Remains for home consumption	2,586

Lead.

Produce of the mines	47,000
Foreign lead imported ore	3,000
	50,000
Lead exported, British and foreign.	18,500
Remains for home consumption	31,500

Steam
power
employed.

(216.) We have before alluded to the extraordinary power of the steam engines employed in these operations, and the improvements which have recently been introduced into the principles of working them, particularly in Cornwall, where great attention and specific reports are made of their performance. Many of these engines are single acting engines, some double acting, and several are worked upon Woolf's principle; but the greatest duty is obtained from the largest of the single acting engines worked expansively. Some of these have cylinders of ninety inches diameter, and for a few days an engine on this scale worked at the rate of duty expressed by 103 millions, but afterwards declined without any sensible cause to 80 millions, at which it continues; that is, the consumption of one bushel of coals in the former instance produced a power equivalent to lifting the enormous weight of 103 millions of pounds a foot high, and settled steadily to lifting 80 millions, whereas a very few years back 24 millions were considered a maximum, and 15 very satisfactory duty. The improvement in this respect is indeed very astonishing, as appears from the following Table of the account of coals consumed at the Dolcoath mine at different depths of level. This Table is given by Mr. Taylor in his *Records of Mining*, as follows.

(218.) The following Table shows the amount of duty performed by the several Cornish engines in the month of February, 1834, for which the writer is much indebted to Mr. Davies Gilbert, who has very obligingly supplied him with it.

Mine.	Engine and the diameter of the cylinder.	Length of the crank.	Length of the stroke, in the cylinder.	Diameter of the fly Wheel.	Number of heads.	Time.	Consumption of coal, in bushels.	Average height which every head lifts, in inches.	Number of times which every head lifts at a stroke.	Number of strokes.	Weight of heads and lifters in pounds.	Pounds lifted one foot high by consuming a bushel of coal	Number of strokes per minute.	Engineers' Names.
Wheal Vor	Old Stamps, 24 inches, double.	Feet 3	Feet 6.5	Feet 12	34	Jan. 25, to Feb. 22.	796	10½	2¼	690190	12640	21577108	17.1	Richards.
Ditto.	South Stamps, 27 inches, double.	2.5	5	15	48	ditto	971	10½	2¼		18760			Richards.
Ditto.	Bratt's Stamps 16½ inches, double.	2.5	5	14.5	24	ditto	1286	10½	2	914070	9460	11767051	22.6	Richards.
Ballaswid-den.	24 inches, double.	2.5	5	13	32	Jan. 29, to Feb. 26.	422	10½	2½	380670	12500	19732597		J. Rowe.

* * * Druce's engine at Wheal Towan has been working with leaky boilers; the counter at Wheal Vor South Stamping Mill has been idle; and the lifts at Truran's engine, Wheal Leisure, have been altering in February month.
MARAZION, February 11, 1834.

*THOMAS LEAN.

Years.

Fathoms level.

Bushels of Coal per month.

Machinery.

1807	160	5,112
1808	170	5,184
1809	170	5,688
1810	180	6,840
1811	180	6,912
1812	180	4,752
1813	180	4,536
1814	180	5,413
1815	180	5,954
1816	180	5,322
1817	180	3,102
1823	180	3,353
1827	180	3,078

The change in 1812 took place in consequence of improvements in the boiler; but that in 1817 seems to have been simply by passing under a new management. The following concise Table shows the individual and aggregate duty of the Cornwall engines from 1813 to 1828.

(217.) A Table of the Duty performed by Steam Engines in Cornwall, showing the Average of the whole for each Year; and also the average Duty of the best Engine in each monthly Report.

Years.	Number of Engines reported.	Average duty of the whole.	Average duty of the best Engines.	Average duty of the engines.
1813	24	19,456,000	26,460,000	
1814	29	20,534,232	32,000,000	
1815	35	20,526,160	28,700,000	
1816	32	22,907,110	32,400,000	
1817	31	26,502,259	41,600,000	
1818	32	25,433,783	39,300,000	
1819	37	26,252,620	40,000,000	
1820	37	28,736,398	41,300,000	
1821	39	28,223,382	42,800,000	
1822	45	28,887,216	42,500,000	
1823	45	28,156,162	42,122,000	
1824	45	28,326,140	43,500,000	
1825	50	32,000,741	45,400,000	
1826	48	30,486,630	45,200,000	
1827	47	32,100,000	59,700,000	
1828	54	37,100,000	76,763,000	

Manufactures.

(219.) *A Statement of the Number of Horses that would be required daily to Perform the work that is accomplished by several Engines: with the Value of one Day's Labour of a Horse in Decimal Parts of a Bushel of Coal; agreeable to the Data of Mr. Watt.*

Mines.	Number of Horses required daily.	Average daily consumption of Coal.	Value of a Day's Labour of a Horse.	
			In coal.	In pence.
Poldice, Sims's engine	449	165	.37	2.9
Cardrew	301	101.6	.34	2.7
Wheal Tolgus, Davey's engine ..	195	56.5	.29	2.3
Dolcoath	324	115	.36	2.8
Binner Downs, Swan's engine ...	404	109.2	.27	2.1
Wheal Darlington	506	101.8	.2	1.6
Marazion Mines, Powlet's engine	232	70.5	.3	2.4
Consols' Mines, Taylor's engine.	466	116.2	.25	2
Ditto, Davey's engine	384	84	.22	1.7
Polgooth	299	63.3	.21	1.6
East Crinnis, Hudson's engine ..	503	152.8	.3	2.4
Great St. George, South engine.	68	22.8	.34	2.7
Wheal Vor, Borlase's engine	380	70.1	.18	1.4
Ditto, Trelawney's engine	513	125.7	.24	1.9
Great Work, Leeds' engine	192	44.3	.23	1.8
Wheal Towan, Wilson's engine.	343	79.9	.23	1.8
Ballaswidden	28	7	.3	2.4

Mines.	Imperial Gallons.	Machinery.
East Wheal Crofty	544.75	
Wheal Tolgus	461.37	
Binner Downs	2014.58	
Marazion Mines	1640.4	
Saint Ives Consols	107.27	
Wheal Reeth	135.7	
Consols and United Mines	2974.17	
Wheal Beauchamp	392.74	
Polgooth	1124.09	
Pembroke	952.22	
East Crinnis	836.79	
Lanescot, Sawle's engine	117.8	
Roche, Rock Mine	250.35	
Wheal Leisure	725.02	
Great St. George	855.26	
Wheal Vor and Carleen	1161.11	
Great Work	398.53	
Wheal Towan	857.24	
Wheal Prudence	134.96	
Wheal Budnick	176.75	
Retallack and Hallamanning	486.35	
Relistian	188.5	
Wheal Darlington	1341.52	
Ballaswidden	120.12	
Levant	23.73	
Ding-dong	44.9	

(220.) *Average quantity of Water per Minute drawn from the Mines, in February, 1834.*

Mines.	Imperial Gallons.
Wheal Unity Wood	491.76
Wheal Unity and Poldice	1114.45
Wheal Damsel	78.06
Wheal Jewell	98.18
Cardrew	702.52
Dolcoath	370.18
Stray-Park	195.53

In reference to the quantity of water drawn by the steam engines from the mines, it should be observed, that some of the engines deliver the water to the adit level, through double columns of pumps; others by Shammal engines, that is, they deliver the water at a level beneath the adit, whence it is drawn by another engine to the adit level. There are other steam engines assisted by hydrostatic engines, in which case the quantity of water cannot be correctly ascertained, and consequently the account is omitted.

T. L.

(221.) *Work performed by the following Steam Engines, in February, 1834.*

Mines.	Engine, and the diameter of the Cylinder.	Load per square inch, on the piston.	Length of the stroke in the cylinder.	No. of lifts.	Depth.	Diameter of the pump.	Time.	Consumption of coal.	Number of Strokes.	Length of the stroke in the pump.	Load in pounds.	Pounds lifted one foot high, by consuming a bushel of coals.	Number of strokes per minute.	Remarks, and Engineers' Names.
		lbs.	Feet.		fms. ft.	Inches.		Bush.		Feet.				
Wheal Unity.	Wood engine, 52 inches, single.	11.5	6.66	1 2 1 2	38 0 35 0 30 3 31 0	9 16 7½ 5	Jan. 31, to Mar. 1.		410290	5.75 5	24624 4094		9.8	Drawing the load in two shafts perpendicularly. Main beam over the cylinder, two bobs and 59 fms. of horizontal rods at the surface, and 55 fms. of horizontal rods under ground. SIMS AND SON.
Ditto.	Western engine, 60 inches, single.	14.25	7.25	4 1 1	72 0 21 5 3 5	16 16¼ 13	ditto	2976	342600	5.75	50818	33638749	8.2	Drawing perpendicularly. Main beam over the cylinder, one balance bob at the surface, and two under ground. SIMS AND SON.
Poldice	Sims's engine, 90 inches, single.	7.6	10	1 5	4 3 111 0	13 17½	ditto	4624	414350	7	69114	43352444	9.9	Drawing perpendicularly, with main beam over the cylinder; one balance bob at the surface, and one ditto under ground. SIMS AND SON.
Wheal Damsel.	Stephens's engine, 50 inches, single.	10.8	9.33	8 1 1	157 0 11 0 5 0	9 6 7	Jan. 31, to Feb. 28	769	157140	7.25	27322	40477241	3.9	Drawing the load perpendicularly 100 fms., and the remainder diagonally. Main beam over the cylinder; one balance bob at the surface. SIMS AND SON.
Wheal Jewell.	39 inches, single.	10	8.5	1 1 1 1 1	32 5 32 3 20 3 11 3 11 0	10 9 7½ 8 6	ditto	564	193990	6	16934	34947092	4.8	Drawing the load in two shafts perpendicularly with main beam over the cylinder, and two bobs and 112 fms. horizontal rods at the surface. SIMS AND SON.

TABLE continued.

Mines.	Engine, and the diameter of the cylinder.	Load per square inch, on the piston.	Length of the stroke, in the cylinder.	No. of lifts.	Depth.	Diameter of the pump.	Time.	Consumption of coal.	Number of strokes.	Length of the stroke in the pump.	Load, in pounds.	Pounds lifted one foot high, by consuming a bushel of coals.	Number of strokes per minute.	Remarks, and Engineers' Names.
Cardrew-Downs.	66 inches, single.	9.35	8.75	1 2 2	fms ft. 4 0 23 3 50 0	Inches. 10 16½ 16	Jan. 31, to Feb. 28.	Bush. 2844	465270	Feet. 7	39958	45759075	11.5	Drawing perpendicularly. Main beam over the cylinder, and one balance bob at the surface. SIMS AND SON.
Wheal Tolgus.	Davey's engine, 70 inches, single.	7.88	10	1 1 2 1 1 1	4 0 29 1 57 3 11 4 11 3 11 4	8½ 10 14½ 14½ 12 8½	Jan. 31, to Feb. 27.	1584	267190	7.5	40447	51169668	6.87	Drawing perpendicularly. Main beam over the cylinder, and one balance bob at the surface. F. MICHELL.
Ditto.	Pryce's engine, 25½ inches, single.	17.3	6	1 1	21 3 11 4	11½ 11½	ditto	800	408240	6	8836	27054064	10.5	Drawing diagonally. Main beam over the cylinder, one balance bob at the surface, and 100 fms. dry rods and an angle bob under ground. F. MICHELL.
Ditto.	Wh. Chance engine, 50 ins. single.	3.3	9	1 1 1	31 2 16 2 13 1	8 8½ 7	ditto		250250	7.5	7835		6.4	Drawing perpendicularly, with main beam over the cylinder. F. MICHELL.
Dolcoath.	76 inches, single.	10.87	9	1 4 4 1	3 0 70 2 75 4 26 5	8 13½ 12½ 12	Jan. 30, to Feb. 27.	3222	314630	7.5	59183	43344383	7.8	Drawing perpendicularly 179 fathoms, and the remainder diagonally. Main beam over the cylinder; four balance bobs under ground, and one at the surface. JEFFRE.
Stray-Park.	60 inches, single.	8	8	1 3 2 1	6 0 72 0 43 0 14 0	11½ 11½ 11 9½	ditto	2016	332380	5.5	33524	30399250	8.24	Drawing perpendicularly 110 fathoms, and diagonally 24 fathoms. Main beam over the cylinder, five bobs and 70 fathoms of horizontal rods under ground, and one balance bob at the surface. JEFFRE.
East-Wheal Crotty.	80 inches, single.	5.08	10.33	1 2 2 1	20 0 45 0 55 3 18 0	10 9 13½ 9	ditto	2556	317530	7.75	34084	32815284	7.87	Drawing in two shafts perpendicularly 63 fathoms, and the remainder diagonally. Main beam over the cylinder, and two bobs at the surface, connected to 180 fathoms of horizontal rods. MAYNE.
Binner Downs.	Swan's engine, 70 in. single.	10.15	10	1 1 1	3 0 40 4 41 3	10 18 17	Jan. 27, to Feb. 28.	3167	449990	7.5	52095	55515225	10.77	Drawing all the load perpendicularly. Main beam over the cylinder. GREGOR AND THOMAS.
Ditto.	Burn's engine, 64 inches, single.	10.9	9.33	1 1 1 1 1	3 1 39 0 28 1 28 4 11 0	8 16½ 15 8½ 13½	ditto	2405	388210	7.75	42211	52805478	9.3	Drawing 4 lifts perpendicularly, connected by 100 fathoms of dry rods. Main beam over the cylinder; one balance bob at the surface, and 3 balance lifts in the shaft. GREGOR AND THOMAS.
Ditto.	Wh. Treasury engine, 50 in. single.	13.6	9.66	1 1 1 1 1	24 1 41 3 15 0 15 0 8 3	6 15 14 11½ 9	ditto	2441	456720	8	32183	48172453	10.9	Drawing perpendicularly, with main beam over the cylinder. GREGOR AND THOMAS.
Ditto.	Gregor's engine, 42 inches, single.	17	9	1 1 1 1 1 1 1	3 0 43 3 27 2 32 0 21 0 10 3 11 0	7½ 13 9½ 7½ 8 7½ 6½	ditto	2246	439780	7.5 6	25146 3878	41484020	10.5	Drawing the load in two shafts perpendicularly. Main beam over the cylinder; 215 fathoms of horizontal rods, connected by two bobs at the surface, and 70 fathoms of dry rods in the shaft. GREGOR AND THOMAS.
Wheal Darlington.	80 inches, single.	11.1	10	3 2 1	65 5 63 1 8 5	19 12 12	Jan. 24, to Feb. 24.	3126	431760	8	69818	77145539	9.67	Drawing perpendicularly. Main beam over the cylinder, and one balance bob at the surface. EUSTIS.
Marazion Mines.	Powlet's engine, 60 inches, single.	12.1	9	1 2 1 1 1	30 0 61 1 40 3 20 0 10 0	10½ 13 7 10 12½	ditto	2187	361870	8	38530	51002656	8.1	Drawing perpendicularly. Main beam over the cylinder, and one bob at the surface. GROSE.

TABLE continued.

Mines.	Engine, and the diameter of the cylinder.	Load per square inch, on the piston.	Length of the stroke in the cylinder.	No. of lifts.	Depth.	Diameter of the pump.	Time.	Consumption of coal.	Number of strokes.	Length of the stroke in the pump.	Load in pounds.	Pounds lifted one foot high, by consuming a bushel of coal.	Number of strokes per minute.	Remarks, and Engineers' Names.
		lbs.	Feet.		fms. ft.	Inches.		Bush.		Feet.				
Marazion Mines.	Tregurtha engine, 40 inches, single.	14.2	7.75	1 1 1 1	27 3 38 3 22 3 22 3	13 7 12½ 8	Jan. 24, to Feb. 24.	2040	613710	6	23076	41652858	13.7	Drawing the load perpendicularly. Main beam over the cylinder, and one bob at the surface. GROSE.
Ditto.	Owen vean engine, 30 inches, single.	24	6	1 2 1 1 1 1	6 0 30 0 25 2 22 2 10 0 9 3	4 6 11 11½ 8 8½	ditto	1914	687650	6	16988	36620057	15.4	Drawing the load in two shafts 60 fathoms perpendicularly, and the remainder diagonally. Main beam over the cylinder, and two bobs at the surface. GROSE.
St. Ives Consols.	36 inches, single.	16.67	7	3 2 1 1	64 2 40 0 18 0 10 4	8½ 8 6 8½	Jan. 28, to Feb. 24.	1044	273550	7	16956	31925171	7.03	Drawing the load perpendicularly 18 fms., and diagonally 101 fms. Main beam over the cylinder; one balance bob at the surface. EUSTIS AND SON.
Wheal Reeth.	36 inches, single.	16.03	7.5	3 1 1 4 2 2	89 0 10 3 30 0 80 0 30 0 60 0	8 6 5 4 4 3	ditto	1198	322960	7.5 4 3	13958 3600 1105		8.3	Drawing perpendicularly 28 fathoms, and the remainder diagonally. Main beam over the cylinder; three bobs and 130 fathoms of horizontal rods at the surface, 180 fms. of dry rods in the shaft, and 25 fathoms horizontal rods connected to four bobs under ground. EUSTIS AND SON.
Consolidated Mines.	Taylor's engine, 85 inches, single.	11	10.33	1 6 2	10 2 193 0 22 4	15 13 17	Feb. 1, to March 1.	3253	300150	7.75	84870	60689029	7.4	Drawing all the load perpendicularly. Main beam over the cylinder; two balance bobs at the surface, one under ground, and a balance lift in the shaft. HOCKING AND LOAM.
Ditto.	Davey's engine, 80 inches, single.	9.9	11.33	8 1	211 0 12 0	12 10	ditto	2352	292610	8.75	64602	70324372	7.25	Drawing perpendicularly. Main beam over the cylinder; one balance bob at the surface, and two under ground, and a balance lift 31 fathoms of 17 inches in the shaft. HOCKING AND LOAM.
Ditto.	Pearce's engine, 65 inches, single.	15.5	9	1 1 8 1 1 1 1	9 0 1 2 199 2 25 3 13 2 8 3	12 11 11½ 11 7½ 5	ditto	1567	189780	7.5	61722	56063821	4.7	Drawing the load perpendicularly. Main beam over the cylinder; one balance bob at the surface, one under ground, and a balance lift in the shaft. HOCKING AND LOAM.
Ditto.	Woolf's engine, 90 inches, single.	10.62	10	8 1	221 3 12 4	4 8	ditto	2617	227030	7.5	90056	58594039	5.6	Drawing perpendicularly. Main beam over the cylinder; one balance bob at the surface, and two balance lifts in the shaft. HOCKING AND LOAM.
Ditto.	Bawden's engine, 90 inches, single.	8.2	10	1 6 1 1 1	15 3 159 1 23 0 11 2 5 3	12 13 13 12 10	ditto	3710	330800	7.5 6	59584 12412	46487118	8.2	Drawing perpendicularly. Main beam over the cylinder; one balance bob at the surface, one under ground, and 50 fathoms of diagonal rods in the shaft. HOCKING AND LOAM.
Ditto.	Shears's engine, 65 inches, single.	12.6	9	5 1 1	136 0 12 0 4 0	13 11 6	ditto	2207	349620	7.5	50276	59733218	8.67	Drawing all the load perpendicularly. Main beam over the cylinder; two balance bobs at the surface, and one balance lift in the shaft. HOCKING AND LOAM.
United Mines.	Cardozo's engine, 90 inches, single.	10.5	9	2 3 3	26 3 70 5 70 5	10 16 15	ditto	4260	363600	8	75108	51285011	9.02	Drawing the load perpendicularly. Main beam over the cylinder, and one balance bob at the surface. HOCKING AND LOAM.
Ditto.	Little engine, 30 inches, single.	13.66	9	1 1	6 5 27 4	12 13	ditto	753	367870	7.5	11576	42414971	9.1	Drawing all the load perpendicularly. Main beam over the cylinder, and one balance bob at the surface. HOCKING AND LOAM.

TABLE continued.

Mines.	Engine, and the diameter of the cylinder.	Load per square inch, on the piston.	Length of the stroke in the cylinder.	No. of lifts.	Depth.	Diameter of the pump.	Time.	Consumption of coal.	Number of strokes.	Length of the stroke in the pump.	Load, in pounds.	Pounds lifted one foot high, by consuming a bushel of coal.	Number of strokes per minute.	Remarks, and Engineers' Names.
		lbs.	Feet.		fms. ft.	Inches.		Bush.		Feet.				
Wheal Beauchamp.	Western engine, 36 inches, single.	15.94	7.75	1 1 1 1 2 1	32 3 21 1 21 1 21 1 10 3 23 0 12 3	8 11 10 9½ 8½ 6 5½	Feb. 4, to Feb. 28.	852	252400	6 4.5	19078 2467	37199227	7.3	Drawing the load in two shafts perpendicularly, with main beam under the cylinder, 328 fathoms of horizontal rods, connected to three bobs at the surface, and 103 fathoms of dry rods in the shafts. HOCKING AND LOAM.
Ditto.	Powning's engine, 36 in. single.	7.2	8	1 1 1	21 3 21 1 5 3	10½ 10 8½	ditto	486	299730	6	9762	36123015	8.66	Drawing perpendicularly, with main beam over the cylinder. HOCKING AND LOAM.
Polgooth.	66 inches, single.	8.54	9.8	1 1 1	30 3 16 3 16 3	20 18 9½	Feb. 7, to March 5.	1647	417390	7.4	38698	72571931	11.14	Drawing perpendicularly. Main beam over the cylinder, and one balance bob at the surface. SIMS AND SON.
Pembroke (Old Mine.)	New engine, 50 inches, single.	7.15	9	1 1	32 1 11 0	15 12	Feb. 6, to March 6.	1050	321850	7	18043	38714263	7.98	Drawing perpendicularly. Main beam over the cylinder; one balance bob at the surface. SIMS AND SON.
Ditto.	Edgcumbe's engine, 40 inches, single.	17.76	9	2 1 2 2 1 2	14 3 30 1 46 3 24 2 12 0 25 0	8 14 9 7½ 7½ 10½	ditto	1314	320310	6.5 6	25693 5638	48956360	7.94	Drawing the load in two shafts perpendicularly, with main beam over the cylinder, and 310 fathoms of horizontal rods, connected to three bobs at the surface. SIMS AND SON.
East Crinnis.	Hudson's engine, 76 inches, single.	11.18	10.33	1 2 1 1	6 0 70 0 31 4 12 2	13 18 17 12	ditto	4278	423060	7.25	70835	50786360	10.45	Drawing all the load perpendicularly. Main beam over the cylinder; one balance bob at the surface, and two balance lifts (40 fathoms of 17 inches) in the shaft. SIMS AND SON.
Lanescot and Fowey Consols.	Union engine, 40 inches, single.	10.2	9	1 1 1 1	42 5 30 5 10 4 8 4	10½ 9 8 7½	ditto		219830	7	16486		5.45	Drawing perpendicularly. Main beam over the cylinder; one balance bob at the surface, and 91 fathoms dry rods in the shaft. W. PETHERICK AND W. WEST.
Ditto.	Sawle's engine, 24 in. single.	15.8	8.5	1 2 1	4 3 43 3 10 5	7 10 8¼	ditto	374	230060	5.5	11045	37367833	5.7	Drawing perpendicularly, with main beam over the cylinder. W. PETHERICK AND W. WEST.
Roche Rock Mine.	36 inches, single.	9.26	8.5	1 1 1 1	21 2 10 0 10 0 10 0	12 11½ 8½ 8	ditto	564	305630	6.8	11648	42883805	7.5	Drawing perpendicularly, with main beam over the cylinder, and one bob at the surface. S. TRETHEWY.
Wheal Leisure.	Truran's engine, 70 inches, single.	11.05	10.0	2 1 1 1	73 5 22 1 12 0 12 1	16 14½ 11½ 10½	Feb. 5, to March 7.		310550	8	53173		7.18	Drawing the load perpendicularly. Main beam over the cylinder. S. TRURAN.
Ditto.	South engine, 66 inches, single.	7.48	9.83	2	62 0	16	ditto	702	142990	7.75	32464	51247453	3.31	Drawing the load perpendicularly. Main beam over the cylinder, and one balance bob at the surface. S. TRURAN.
Great St. George.	North engine, 60 inches, single.	10.36	10	1 2 1	6 0 62 3 11 0	10 17 17½	ditto	1998	208320	6.5	45063	30539993	4.82	Drawing perpendicularly. Main beam over the cylinder, and one bob at the surface. S. GROSE AND J. WEST.
Ditto.	South engine, 40 inches, single.	15.38	9	2 1	67 0 10 0	12 13	Feb. 5, to Feb. 22.	388	102140	7.5	23191	45787282	4.17	Drawing perpendicularly. Main beam over the cylinder, and one balance bob at the surface. S. GROSE AND J. WEST.
Ditto.	Devonshire's engine, 70 inches, single.	9.58	10	1 1 3	1 1 43 1 69 2	9 9½ 17	Feb. 5, to March 7.	2358	230030	7.5	49146	35957552	5.32	Drawing perpendicularly. Main beam over the cylinder, and one balance bob at the surface. S. GROSE AND J. WEST.

TABLE continued.

Mines.	Engine, and the diameter of the cylinder.	Load per square inch, on the piston.	Length of the stroke in the cylinder.	No. of lifts.	Depth.	Diameter of the pump.	Time.	Consumption of coal.	Number of strokes.	Length of the stroke in the pump.	Load, in pounds.	Pounds lifted one foot high, by consuming a bushel of coal.	Number of strokes per minute.	Remarks, and Engineers' Names.
		lbs.	Feet.		fms. ft.	Inches.		Bush.		Feet.				
Wheal Vor.	Borlase's engine, 80 inches, single.	12.26	10	6 1	188 2 7 4	14 10	Jan. 25, to Feb. 22.	1964	265860	8	77070	83462546	6.59	Drawing perpendicularly 160 fathoms, and the remainder diagonally. Main beam over the cylinder; one balance bob at the surface, and four ditto and a V bob under ground. RICHARDS.
Ditto.	Trelawny's engine, 80 inches, single.	15.49	10	6 2 3 1 1	150 5 45 1 33 0 18 3 6 0	14 15 16½ 9½ 9½	ditto	3520	283590	7.5	103802	62721326	7.03	Drawing perpendicularly 135 fathoms, and the remainder diagonally. Main beam over the cylinder; three balance bobs under ground, and one at the surface. RICHARDS.
Ditto.	Woolf's engine, 53 inches, single.	16	9	1 5 1	3 0 134 0 10 0	10 12 10½	ditto	1703	264480	7.5	42446	49439744	6.55	Drawing perpendicularly 131 fathoms, and diagonally 20 fathoms. Main beam over the cylinder; two bobs under ground, and one at the surface. RICHARDS.
Ditto.	Carleen engine, 45 inches, single.	16.86	6.8	1 1 5 1 1 1	28 2 29 3 90 1 11 3 7 2 13 1	9½ 8 10 10½ 8 8	ditto	1231	316740	5.6 4.8	31088 1724	46923834	7.85	Drawing the load in two shafts perpendicularly. Main beam under the cylinder; two bobs and 117 fathoms of horizontal rods at the surface. RICHARDS.
Great Work.	Wheal Breage engine, 60 inches, single.	10.25	9	1 1 4 1	10 3 32 3 105 0 11 0	15 12 10 8	ditto	1602	245040	7	37321	39960028	6.07	Drawing 90 fathoms perpendicularly, and 87 fathoms diagonally. Main beam over the cylinder; one balance bob at the surface and one under ground. RICHARDS.
Ditto.	Leed's engine, 60 inches, single.	11.42	8	1 5 1	35 1 126 5 4 3	12 10 8	ditto	1242	321260	7	36890	66794661	7.96	Drawing perpendicularly 108 fathoms, and the remainder diagonally. Main beam over the cylinder; one balance bob at the surface, and one balance lift (30 fathoms of 14 inches) the shaft. RICHARDS.
Wheal Towan.	Wilson's engine, 80 inches, single.	11.11	10	1 3 1	44 5 95 1 12 0	13 16 14	Feb. 4, to Mar. 8.	2556	302340	8	69826	66075720	6.56	Drawing perpendicularly 92 fathoms, and diagonally 11 fathoms. Main beam over the cylinder; one balance bob at the surface, and two angular shieves under ground. GROSE.
Ditto.	Druce's engine, 80 inches, single.	8.75	10	1 1 2 2	34 0 46 4 51 0 32 3	11 14 13½ 12	ditto	2502	349160	8	55010	61414201	7.47	Drawing perpendicularly 82 fathoms, and diagonally 33 fathoms. Main beam over the cylinder; one balance bob at the surface, and one ditto, and an angle bob under ground. GROSE.
Wheal Prudence.	33 inches, single.	14.6	8.75	1 2 1	44 3 56 1 11 5	6 9½ 10½	Feb. 5, to Mar. 7.	946	281550	6.75	16187	32518801	6.5	Drawing perpendicularly. Main beam over the cylinder, and one balance bob at the surface. J. WEST.
Wheal Bucknick.	36 inches, single.	11	8.5	2 1 1 1 1	7 4 19 3 31 2 11 5 6 0	5 12 10 9 8	ditto	650	249940	6.25	15290	36745986	5.78	Drawing the load in two shafts perpendicularly, with main beam over the cylinder, 86 fathoms of horizontal rods and two bobs at the surface. GROSE.
Wheal Retallack.	North engine, 36 inches, single.	17.7	7.84	1 2 2 1	7 0 54 3 32 2 10 0	6 12 10 8	Jan. 27, to Feb. 25.	1342	306670	5.75	24490	32179212	7.34	Drawing the load 47 fathoms perpendicularly, and the remainder diagonally. Main beam over the cylinder, and one balance bob at the surface. EUSTIS AND SON.
Hawthorn- ing.	Hawkin's engine, 36 inches, single.	14.6	8.66	1 1 1 1 1	14 4 31 4 18 1 10 3 11 0	9 12 12 10 8	ditto	1348	380010	6.52	20585	36269036	9.1	Drawing perpendicularly. Main beam over the cylinder, and one balance bob at the surface. EUSTIS AND SON.

TABLE continued

Mines.	Engine and the diameter of the cylinder.	Load per square inch, on the piston.	Length of the stroke in the cylinder.	No. of lifts.	Depth.	Diameter of the pump.	Time.	Consumption of coal.	Number of strokes.	Length of the stroke, in the pump.	Load, in pounds.	Pounds lifted one foot high, by consuming a bushel of coal.	Number of strokes per minute.	Remarks, and Engineers' Names.
Wheal Relistian.	60 inches, single.	9.4	9	1 2 1 1 1	28 1 70 4 11 4 10 3 8 0	9 12 11 10½ 9	Jan. 27, to Feb. 25.	1540	213830	7.5 6.5	30736 1325	33203702	5.12	Drawing perpendicularly 98 fathoms, and the remainder diagonally. Main beam over the cylinder; one balance bob at the surface; and fathoms of flat rods under ground.
Ballaswid-den.	24 inches, single.	12.08	7	2 1 1 1 1 1	23 1 17 3 22 0 16 0 16 0 10 0	4 7 5 6½ 5½ 3½	Jan. 29, to Feb. 26.	195	258020	6	6369	50563980	6.4	Drawing the load in three shafts perpendicularly, with main beam over the cylinder and 3 bobs and 280 fathoms horizontal rods at the surface. J. ROWE.
Levant.	26 inches, single.	10	4	5	140 5	4½	ditto	288	246630	4	5840	28115544	8.6	Drawing perpendicularly 75 fathoms, and diagonally 70 fathoms. Main beam over the cylinder; one balance bob at the surface, and one under ground; and three angle bobs in the shaft. F. MICHELL.
Ding-dong.	30 inches, single.	7.6	6	2 2 2 1	37 3 29 3 25 0 15 3	4 6 5½ 4½	ditto	324	247450	6	5372	24616692	6.1	Drawing diagonally with main beam over the cylinder, and one bob at the surface. T. BOLITHO.

Estimate of the aggregate power of the steam engines in mines.

(222.) It is difficult to form a correct estimate of the aggregate power of these engines; the particulars are always referred to the combustion of one bushel of coals as a unit without reference to the time of consumption; but by comparing a few cases, and computing the actual weight raised per minute, it appears that although these engines work very economically, as far as regards consumption of fuel, they are not individually equivalent in horse power to common engines of equal diameter of cylinder. From the comparison of the actual load lifted in a minute with the diameter, they appear to be deficient in power in about the ratio of eleven to fourteen, as compared with usual engines.

By estimating each engine in nominal horse powers according to its diameter by the Table, Art. 209. it appears that the aggregate number of nominal horse powers of the Cornwall engines amount to 4182, but as they are of less power, in the ratio of eleven to fourteen, than common engines of the same diameter, this reduces the horse powers to 3362. This nominal power is, however, eight hours work per day, whereas these engines work all the twenty-four hours, so that they are, in effect, equal to 10,086 nominal horse powers, which, as we have seen, Art. 4. is equal to 15,129 actual horses' labour; and each horse being equal to 5 men, it follows that the work performed by the Cornwall engines is equal to the power of 75,645 men; and assuming the steam power employed in other mines in Great Britain in proportion to their quantity of mineral product, the whole amount of power will be equivalent to 500,000 men.

Since the above was written we have been favoured with the following curious calculation relative to the power of these engines, with reference to the power requisite to raise one of the great Pyramids of Egypt. The comparison was before made by Baron Dupin; but the following, which is by Mr. Davies Gilbert, is founded on more exact data, and extends to other comparisons, strongly

illustrative of the power of the Cornish steam engine: it is an extract from a letter addressed to H. T. de la Beche, Esq. dated Feb. 23, 1834.

"I have not lost any time in answering your queries respecting our engines and the Pyramid; the base of the first Pyramid is said to be a perfect square of 687 feet, and that each face is an equilateral triangle. Its height must then be $687 \times \sqrt{\frac{1}{3}}$ or 485.78 feet. And its cubic content $687^3 \times \frac{1}{3} \sqrt{\frac{1}{3}} = 18,040,000$, or about 18,000,000 of cubic feet. And assuming the specific gravity of the materials at $2\frac{1}{2}$, the weight will be 1,253,000 tons, about 2,807,000,000 of pounds. The space through which the materials of a Pyramid are raised is well-known to be the same as would be gone through by raising the whole to the height of the centre of gravity, which is one quarter part, or $\frac{484.78}{4}$, giving 374,190 millions of duty.

"In the best Cornish engine a bushel of coal produces above 100,000,000 of duty, consequently a ton of coals, or bushel weighing 84 pounds, will do $26\frac{2}{3}$ as much, or 2,666,000,000 of duty; and consequently 127.82 tons of coal would raise the Pyramid. Now the steam engines of Cornwall, and the smelting furnaces in Wales, are said to consume at the least a thousand tons of coal daily in raising and in manufacturing copper; therefore that quantity of coal would be equal to raising 2853 Pyramids in the course of a year.

"To obtain, however, the average of the best engines in constant work about a third must be taken off, leaving then above eighteen hundred Pyramids.

"The mines of Cornwall are stated in the printed Report of the engines for the last month, January 1834, that they are altogether lifting 20,000 gallons a minute, but the heights are not mentioned; but as the deep mines produce by far the largest quantity of water, the mean height may perhaps be taken at 120 fathoms, or

Manufac-
tures.

720 feet. In that case the duty performed each minute will be 20,000 gallons $\times$ 10 pounds $\times$ 720 = 144,000,000, or 144 millions in a minute.

"The New River has been found to flow with the velocity of three feet in a second, through a channel four feet wide, and four feet deep; $4 \times 4 \times 3 = 48$ feet in a second, or 2,880 feet in a minute. Now a cubic foot weighs 62.32 pounds nearly, consequently 179,499 pounds of water flowed by in a minute.

"The whole course of the New River is 42 miles, and the descent 5 inches on a mile; 210 inches = 17.5 feet in the whole. But $179,499 \times 17.5$ give 3,141,000 in a minute.

"But the steam engines of Cornwall, performing an actual duty of 144,000,000 in a minute, are equal to forcing back to its source near Hertford the New River nearly 46 times repeated.

"The 20,000 resisting the engine in a minute = 3209 cubic feet, or 1850 millions of cubic feet raised 720 feet in the year. The solid content of Westminster Hall being little more than 1,000,000 of cubic feet.

Every thing relative to the Pyramid was made three times too great, by squaring the base and multiplying by the height, instead of one-third its height. It is corrected in the preceding calculations.

Two other minerals, iron and coal, not included in the above estimate, remain to be noticed; but as these are frequently found in the same vicinity, and the working of them differs essentially from the mines of copper, tin, and lead, it is proposed before we proceed to enter upon a description of these, to endeavour to explain the processes followed in working the copper mines of England, and particularly those of Cornwall.

Definition
of terms.

Definitions of the Terms and Description of the Processes employed in working Copper and Tin Mines.

(223.) It does not belong to this Essay to enter into a Geological examination of the theories which have been advanced relative to the formation of the veins of metals with which various rocks are interspersed, nor the rules by which the Mineralogist is guided in following or intercepting them. These are more appropriately discussed in our Treatises on GEOLOGY and MINERALOGY. Our business here is only with the mechanical operation of extracting the ore from the rock, and of reducing it to a proper state for being converted into the pure metal. It will be proper, however, before we proceed, to define a few terms peculiar to the mines, and in some cases to the Cornwall mines only.

Pl. xvi.

Lode is a term used to denote any regular vein, whether metallic or not, but more commonly it implies a vein containing metallic ore. In mining districts these lodes are observed to have a prevailing direction, but by no means general. In Cornwall and Devon the prevailing direction of the lodes is East and West.

The underlay of a lode is a term used to denote the direction of its inclination with regard to the horizon, which, in the same districts, is commonly to the North, although some productive lodes are found which dip in a Southern direction.

Veins which intersect or cross the East and West lodes nearly at right angles are called *cross lodes*, or *cross-courses*, but when they differ greatly from this they are called *counters*. These cross veins are seldom productive of copper or tin in much abundance, but lead is sometimes raised from them in great quantities.

The size of lodes, or width, vary from a few inches to several feet, but from two to four feet is considered profitable to work, if fully impregnated with metal. The size, however, is very uncertain in the same lode, varying frequently from several feet to a mere branch, after which it will sometimes open again to its original size, or exceed it. These veins extend through rocks of different characters, without deviating from their line, although they frequently vary in width and productiveness as they pass from one to the other. Thus a vein that is large and productive in soft blue killas, will, by passing into harder, become less in size and poor as to metallic percentage; another may be rich in hard ground and poor in soft, but this is not so frequent as the former case. The deposits of metals are also as uncertain in the lodes as the width of them, the ores being found to occupy only certain parts, and differ considerably in extent, both in length and depth. No lode, we believe, is known to preserve a regular impregnation of metal, although some are much more constant in this respect than others, but generally it is partially distributed, and when found in pretty large quantities, it is called by the miners *bunches* or *shoots*. Although bunches or shoots of ore have no regular form either in horizontal or vertical extent, yet the tendency to a partial direction or dip in a lode may be observed in every such bunch, and they are frequently parallel in the same vein; and where the dip or underlay is to the North, the shoots of ore may frequently be observed to dip to the West in the lode. This rule, however, is liable to great exceptions, as is also the direction of the vein, as well as that of its underlay. In the great Kappisberg mine in Sweden two of the principal veins are in direction nearly at right angles to each other, and their underlay varying also to nearly the same extent.

Lodes continue to indefinite lengths, and to unknown depths; it is very difficult to determine whether the termination of any regular vein has been reached, as instances occur of their having become so small as to be scarcely visible, and yet afterwards on pursuing them they have resumed their usual size; but when a lode has continued small, either in length or breadth, for any considerable distance, it is usually abandoned, so that complete evidence on this point is never ascertained. Lodes are as perfect at the surface of the mountain as in their greatest depths, and may be traced regularly by removing the soil with which the rock is covered. This is constantly done by the miner when he is about to undertake new operations; and this gave rise to certain privileges formerly conferred upon the tin miners of Cornwall, who were permitted to open grounds of other persons in such pursuits. This was called *shoding*. The width, however, of a lode at the surface is no certain sign of its size at any depth; for frequently when broad at the surface they become of little size as we descend; and on the other hand lodes of small width on the surface become of great size at some fathoms down.

Lodes are seldom found to preserve a directly perpendicular line, and even their underlay or inclination from the perpendicular is not uniform throughout. These will vary from one foot to four feet per fathom, and some even have still greater inclination than four to six, but they are seldom considered to offer so promising a prospect as those of less inclination.

When it is intended to sink perpendicular shafts the underlay of the lode must be ascertained, in order to meet them at certain depths, and according to this incli-

Machinery.

Manufac-
tures.

nation the shaft must be commenced at the proper distance at the back of the vein; but sometimes shafts are sunk upon lodes, are not then of course perpendicular, but partake of the inclination of the lode itself; sometimes, also, after proceeding perpendicularly for some distance, the miner will take the direction of the lode, and thus form inclined planes, connecting one level with another: these levels are driven on in the substance of the lode, follow its direction, and are the principal means by which discoveries of ore are made and pursued.

It has been stated that a vein or lode may be traced on the surface of the mountain by removing the soil, or by shoding, and it is thus that many veins have been discovered; or they may be discovered accidentally on the formation of roads, ditches, and such like processes: the latter case, however, is one of pure accident, the former is pursued for the express purpose, some indication having been observed by detached fragments of ore being found, or by springs of water being discovered impregnated with metal.

Another method by which veins are discovered is in running an adit for the discharge of water from some mine already in work, or for any other purpose; but such levels, when they are intended to be made for such purpose, should be carried across the prevailing direction of the lodes, being of course by this means more likely to intersect some unknown vein, than when driven in any accidental direction. There are, however, minute points for observation on the surface, which guide the experienced eye of the miner in these pursuits, which it is impossible to describe, and which indeed, if it were possible, would not properly belong to this article, which only professes to describe the actual practical operations after the lode itself and its direction have been ascertained. We shall therefore now suppose that the position of the vein is known, and confine ourselves merely to a description of the mode of sinking, working the levels, draining and pumping the water, raising the ores, and stamping, and otherwise reducing them to a state fit for smelting.

Operation
of sinking.

Pl. xvi.
Fig. 1.

(224.) *Operation of sinking.*—This is, of course, in the commencement very simple. Two or more men are employed digging, while two others at a common winch and barrel raise the soil. After a certain depth, the labour of raising becomes greater; and then sometimes a sort of capstan is erected, and a greater number of men are employed in the latter operation. This is afterwards changed, as the depth increases, to the employment of a horse mill, working what is called a *whim* or *whimsy*, that is a large hollow kind of drum, on which the rope is wound, which brings up the materials, and which mode is pursued afterwards throughout the working, but the horse mill is ultimately substituted by a water wheel, the steam engine, or other Machine. When the first shaft is run out of the perpendicular, taking the inclination of the lode, then of course the material is brought up on an inclined plane; but generally, whatever may be the direction of the working shaft, a vertical shaft is afterwards sunk to communicate with some of the levels, and through which the ore is raised, and by means of which the mine is kept dry by pumping, if there be no other means of discharging the water by an adit run into the sloping face of the mountain. As the work proceeds, however, the shaft becomes deeper than the adit, and then Machinery, such as has been described, must be had recourse to: when a supply of water can be had to work a water wheel it is preferred for its

cheapness, but generally we may say the steam engine Machinery. is adopted in most English mines. We have, indeed, shown that in Cornwall alone the steam engine power employed is equivalent to 15,000 horses, or to 75,000 men.

(225.) When the shaft is sunk sufficiently deep, and it becomes desirable to pursue the lode horizontally, it is stopped for a time, and a level is pursued on each side of it; and this is usually continued in two opposite directions upon the course of the vein. The ends of these levels being driven to some distance out of the way of the shaft, sinking may commence again and continue till it is thought proper to drive another level, and then a succession of these galleries or drifts are opened under each other, and the vein is thus divided into parallel portions, which are left to be worked for the ore contained in them. These are in Cornwall commonly called *backs*. New openings are made from the surface to these levels, by sinking more shafts at proper distances, and communications from one level to another are sometimes formed by sinking small underground shafts, in which the soil is raised by the common windlass. When a mine has arrived at this state, and a sufficient supply of ore seems probable, proper engines are erected, provided with a requisite power to admit the constant deepening of the mine, by keeping the bottom of the engine shaft dry, so as to be regularly sinking; ventilation is also now to be attended to and put in an effective state, by means of the different shafts and levels, and Machines constructed for the purpose of bringing up the ores and waste to the surface, worked as before stated either by water wheels or steam engines; and when thus provided, the mine is said to be, and is, in fact, in due course of working. These shafts and levels are kept constantly sinking and driving to lead to further discovery, or to open more of the lode for working; and the parts of the vein or lode left between the passages thus made are worked away, where the ore will pay the expense of so doing, by men who contract for this work within certain limits, being paid a proportion of the value when merchantable, which is called tribute, and which varies with the degrees of facility with which the ore can be procured, either from the different states of richness of the lode or the hardness or softness of the rock which must be broken to obtain it. A considerable improvement has taken place in this kind of working of late years, by which it is said half the expense of the labour has been saved; this is by working from the lower level upwards, instead of proceeding from the upper level downwards; in the former case the rubbish being left in the place where it falls, whereas in the latter it has to be removed.

The ore is usually conveyed in wheel barrows through the levels under ground by boys to the nearest shaft, and there raised in buckets or *kibbles* to the surface; these kibbles are received in some cases on a board slipped under them when slightly above the surface, and the ore thence removed to its proper places for undergoing subsequent operations. These latter require various hands, principally women and children. The object being to separate from the ore both the stony and sparry waste, as also the mundic and other useless metallic matter with which it is combined; operations performed by hammers and requiring some skill and practice. The better parts of the ore being thus separated, are reduced to a proper size by passing them between two cylinders of iron of unlevel surfaces, or by flat hammers, but usually now by the former method. The coarser parts

Modes of
working.

Manufac-
tures.
Pl. xvi.
Fig. 4.
Description
of stamping
mill.

require much more labour; they are first reduced by the stamping mill, and then undergo the operation of sifting and washing. A stamping mill is represented in plate xvi. fig. 4; this is worked by a water wheel or steam engine, but in Cornwall very frequently by the latter. The mill consists of a long coffer or strong box, made of the firmest timber, and the ore is conveyed to it by a trough: it is not suffered to fall into the trough at once, but is stopped at the mouth by a cross board, and water is turned upon it, which washes in a proper supply. In this coffer there are several stampers placed between strong timbers, having braces or cross pieces on each side to keep them steady, and to assure their vertical direction; their heads are of iron, weighing from thirty pounds upwards, according to the nature of the work to be performed; and the stampers, to the ends of which these heads are fixed, are about eight feet in length, and about eight inches in breadth, having in-timbers or guides between them, as seen in the figure: two tongues are attached to the back of each, which are caught by wipers fixed on a barrel turned by the engine. These wipers are so placed as to catch the tongues on the stampers, and thus to raise them by two lifts, when they fall with great force on the ore beneath. The frequent and powerful blows thus given soon reduce the large masses into a sort of sand, which is washed out of the trough by the continual current of the water made to pass through the coffer. The powdered ore is then conveyed out of the trough into what is called the *launder*, which is a trench cut in the floor, about eight or ten feet square. This is stopped at the lower end by turf, so that the water is all suffered to pass away, and the powder of the ore stopped. Another method of working these stampers has been lately proposed by Mr. Hague, and is in progress of adoption in the Cornwall engines, by giving momentum to those stampers by means of a vacuum, on the same principle as that employed in coining. We have already, in Art. 208, shown the method by which the power of a steam engine may be made available at any required distance from the engine itself; and in this way that vacuum principle is conducted to cylinders, to the piston of which the stampers are affixed, and so arranged that their bottom part is open to the vacuum, and their upper part to the atmosphere to give the blow, and the contrary to raise them; the efficiency is thereby rendered much greater, and more precision is introduced into their action than in the common method. Moreover, by this means the power of an engine may be carried down to any level of a mine having an adit, and the stamping and washing take place there, instead of being at the pit mouth, or, as frequently is the case, at some considerable distance from it; by this means a great quantity of matter is carried away at the adit, which must otherwise have been brought to the surface, and, consequently, much labour is thus saved, particularly in poor mines.

The management of these surface operations is usually confided to a *dresser* or *grass captain*, who regulates the whole, the expense being borne by the men who raise the ore on tribute, and who take their proportion of the value according to the amount of the sales, and, therefore, pay every previous charge.

The erections on the surface of a mine comprise, besides the steam or water engines, whims, stamping mills, and sheds on the dressing floors, a suitable counting-house for the captains and clerks, pay-offices, &c.;

VOL. VII.

also blacksmiths' and carpenters' shops, timber house, Machinery. and every other attachment which the constant wear and frequent repairs to be made render necessary, which it is difficult and unnecessary to particularize more at length in this place.

(226.) *Pumping*.—We have hitherto spoken of pump- Pumping. ing as a simple process; but it will readily be conceived, in mines of 200 fathoms deep, that much difficulty must attend this operation, which will require some particular description. A pump rod 1200 feet long is not managed with the facility of those which more commonly fall under the observation of the general reader. Some lines of illustration will, therefore, form a necessary part of this article. In plate xvii. fig. 1, 2, we have given a representation of a shaft of a mine, with the ladders for descending and the pumps for raising the water. For this interesting figure we have been indebted to the *Records of Mining* by Mr. Taylor; and from the same Work we have also made an abstract of the explanation.

As water can only be raised about thirty feet by suction, it seems to have been concluded that neither could it be by lifting; and thus it appears the lifting pumps for mines are described by Agricola. At what time this erroneous view of the subject was first corrected does not appear; but Delins, who wrote his Work on mining in 1765, describes what he calls the low pumps and the high pumps; and he reasons on the advantages of the latter as if they were not then generally understood, or in common use. This is not extraordinary, as even at this time it is not uncommon to have it propounded that a lifting pump can only raise water about thirty feet; thus confounding the height to which water can be raised by atmospheric pressure with that to be obtained without other alteration of the Machine than extending the length of the pipe upwards above the piston. By this construction, as the fluid cannot return through the valve of the piston, the column will go on increasing above it at each successive stroke till it reaches the top of the pipe, and will afterwards continue to flow out. This is the simple form of the lifting pump of mines, by which, with one lift and with one piston, water is often raised 150 or 180 feet, equal to five or six times the height due to atmospheric pressure. Delins states the advantage of these high pumps, observing, "that as the depths of the shafts are generally very considerable, and too much for a single pump, a number must be applied, one over the other, so as to raise the water into the adit. Each one discharges its water into a cistern; in this is fixed the suction pipe of the pump immediately above, which lifts the water into another cistern. These columns of pumps are of different heights, and the preference of one certain height over the other is a matter much disputed.

"As to the charge of water, in long pumps as in short ones, there is not the least difference as to the proportion of power required in the Machine to raise it, while the cylinders, or working barrels, are equal; for if, in a depth of thirty fathoms, there are two lifts of pumps of fifteen fathoms each, or six lifts of five fathoms, which are all of the same diameter, the load which the Machine has to overcome is perfectly equal, and, consequently, no difference in this respect exists. It is then a question to be considered, whether from other circumstances the one is preferable to the other. Let us, therefore, compare one of the lifts of pumps of fifteen or sixteen fathoms with three lifts of five fathoms each.

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Manufac-
tures.

The three short lifts will have three working barrels, three pistons or boxes, three valves beneath, and three times as much leather; and in the rods and connections there will be three times as much iron-work as in a long lift.

"It is certain then, that the consumption will be triple, and cause great additional expense, when the working barrels and the boxes are of brass. If, also, the power of the Machine is diminished, by want of water way in the suction pipes or wind bores, this evil, which ought chiefly to be avoided, is, by the greater number, much increased, and in short lifts three times as great as in the long ones.

"It is again very clear, that the piston or box causes a great deal of friction in rising and sinking in the working barrel; and, consequently, with the greater number ought to be estimated as threefold. From all these circumstances, it is reasonable that we should prefer long lifts of pumps to short ones; yet it may be objected to the latter, that the pipes, on account of their own height, and that of the column of water they contain, are subject to leak. This may be true where they are made of wood, and when the length is too much extended; nevertheless, experience shows that those resist pressure perfectly, and do not leak to a height of fifteen or sixteen fathoms, if they are properly bound with iron hoops.

"It has been objected, also, that the friction of the boxes is more considerable on account of the greater load, that it is necessary to have more timber in the shafts to sustain the pumps, and that it is more difficult to draw the boxes to change the leathers; all which are trifling considerations, compared with the real advantages that the long pumps possess over short ones." These observations, made in the earlier stages of the application of this very important apparatus, have been proved to be correct in the further experience of their use. In England, where iron pipes have of late years been substituted for those made of wood, and the leakage in that manner avoided, which Delins was obliged to admit might limit the length of columns of pumps to 15 or 16 fathoms, we have been enabled to extend the lifts with advantage to 30 and even 40 fathoms in height, so that mines which in this Country are commonly drained by pumps to the great depth of 160 or 180 fathoms, have only five or six columns of pumps for the purpose.

Description
of the
pumps.
Pl. xvii.
Fig. 1, 2.

(227.) In our plate xvii. fig. 1 and 2 are intended to represent mine pumps, supposed to be working in a shaft about ninety fathoms below the adit, consisting of three lifts. A is the upper part of the shaft above the adit level; B the adit or level into which the water is pumped, and by which it passes off to some opening or out-fall in the side of the hill; C is the main rod which gives motion to the pistons of the different lifts of pumps either buckets or plungers. This rod vibrates up and down, being impelled either by a steam engine, water wheel, or other appropriate Machine; D, D, D, set-offs on the main rod for connecting the pump rods of the different lifts; E the cistern of the upper column of pumps, which delivers to the adit; the cistern receives its supply of water from F, the *collar launder* of the middle column; G is the cistern of the middle column; H the *collar launder* of the lower, having drawing pump and iron pipes. Generally, in this Country, all the pipes are iron, but in the plate the upper or standing pipes are represented as formed of wood, to indicate how this

material may be employed in Countries or situations where the expense of iron pipes might be thought objectionable. It will readily be seen by the figure, that the lower lift only is worked by what is termed the lifting pump, the other two being forcing pumps, worked by solid plungers. Suppose this pump in action, and the main rod ascending, by this motion vacuums are formed in the three working pipes K, L', L'', and the water rushes to supply these vacuums, first from the water in the well filling the pipe K, and from the cisterns G and E into the plunger pipes L', L''. The water in the pipe K is then retained by means of a common clack box at L, and in L', L'', by valves placed at N' and N''. Now on the downward stroke, the valve in the bucket K of the lifting pump, opening upwards, admits this bucket to descend, while the plungers K', K'' force the water through the H pieces which unite the plunger pipe with the standing pipe through the valves at O' and O'', the latter forcing water up to the adit B, where it is discharged, and the former into the cistern F, to supply the vacuum in L' formed by the next ascent of the plunger K''. No water is raised by the descent of the bucket rod in K; but this takes place, of course, during the ascending stroke, so that in the ascending stroke the water is raised in the lower lift, and during the descending stroke in the two upper lifts. By this arrangement, the down stroke of the engine, which corresponds with the up stroke of the rod, is employed in raising the bottom lift of water, and the whole weight of the pump rod, plungers, &c.; and it is by the weight of the latter only that the plungers raise the water in the two upper lifts.

By this means the counterweight, which would be necessary if all the pumps were on the common lifting principle, is avoided; and as this counterweight, to balance such a length of rod and plungers, must be enormous, great convenience and economy is thus attained; besides that the plungers, having no friction or wear except at the stuffing box through which they work, and which packing is readily tightened by the proper collars provided for the purpose, no stoppages of operation are thus occasioned beyond what two or three men can readily correct; whereas in the common buckets the wear from gritty matter, and from the corrosion of the water, is such as to render repairs continually necessary.

It will be seen in the figure, that in order to facilitate any repairs or correction in the valves, square plates are screwed on the face of the valve boxes, which may be removed, the repairs made, and the plates replaced in the least possible time. The operation of the valves above referred to, will be readily comprehended by the figures given in the plate; it is only necessary to state, that an iron bow is attached to the lower box for the convenience of drawing the clack, and that rods are placed below for guiding it again into its place when the repairs are completed.

The further processes to which the different ores are submitted to reduce them to pure metals, is given under the head SMELTING.

(221.) *Iron and coal mines.*—We have hitherto confined our attention to mines of copper, and such metallic ores as occur in veins; we are now to describe the method of conducting mining operations in those cases in which the mineral is deposited in strata or beds, as is generally the case with coal and iron, but the methods of working are so nearly the same in these two cases that a

Machinery.

Coal and
iron mines.

Manufac-
tures.

description of the one will apply equally to the other. The immense quantity of coal requisite for reducing iron ore to the metallic state is such, that if these two minerals were not found in the same vicinity, at least in this Country, it would be impossible to produce the metallic iron at such a price as to be marketable. It is fortunate, therefore, that this contiguity has place in so many districts in England. In Wales, generally, both the iron and the coal lie in mountains which are entered in their face; and the operation of mining consists in simply excavating a tunnel, or driving a head, as it is technically called, into the side of the hill, the bottom of which serves as a drain to the water of the mine, while the mineral, whether ironstone, or coal, is brought out in small waggons called trams, on roads of iron of the old construction, and which, from the name of the carriage, are called tram roads. The steam engine, therefore, in these cases, is wholly dispensed with for the purposes of the mine. These over-ground workings, however, are not general; even in Wales and in many parts of England both minerals are raised from great depths. The operations in deep mines being, as above stated, so exactly the same for both coal and iron, it will be sufficient for our purpose to give a description of one; and as the working for coals in the neighbourhood of Newcastle is conducted on the grandest scale, and carried to the greatest depths, it will perhaps be most interesting and instructive to the reader.

History of
iron mines
in England.

(229) We have been enabled in the preceding part of this article to give some slight sketches of the history of the tin and copper mines of England; but the period at which our iron works commenced, seemed to have wholly escaped the records of historians; its history being a complete blank till about the year 1577, and all we learn then is, that iron was made in England at that time, but was dearer than foreign iron. This notice is given by Holinshed; and in 1678, a short Memoir was printed in the *Phil. Trans.* No. 137, by Henry Powle, Esq. descriptive of some iron works in the Forest of Dean, and which it appears had been carrying on for some years before, as it is said "that the country formerly bore very stately oaks which are at this time nearly destroyed by the extension of the iron works."

It is also stated, "that in former times, when their works were few and their vend small, they made use of no other bellows but such as were worked by the strength of men, by reason of which their fires were much less intense than the furnace they now employ." "This is furnished with two huge pair of bellows whose noses meet at a little hole near the bottom; these are compressed together by certain buttons, placed on an axis of a very large wheel, which is turned about by water, in the manner of an overshot wheel; as soon as these buttons are shot off, the bellows are raised again by the counterpoise of weights, by which they are made to play alternately, the one giving its blast while the other is rising."

In another part of the same Paper it is stated, that several attempts had been made to introduce the use of sea-coal in these works instead of charcoal; the former being to be had at an easier rate than the latter; but that the trials had not been attended with success. In 1693, we have another communication to the Royal Society, No. 199, by Mr. John Sturdy, describing some processes followed, and the nature of the ore employed

at iron works in Lancashire. They have in this country, it is said, "several sorts of ironstone and of different natures, for some make cold short iron, such as is brittle when it is cold, another sort makes red short, such as is apt to break when it is hammered at a dark red heat, and is therefore never melted down but in mixture, and so it yields an indifferent good sort of iron." Of late, it is observed, they have made it much better by melting the same metal over again, and by using turf and charcoal, whereas formerly their fuel was only charcoal. "They once tried pit coal but with bad success."

Machinery.

These notices, although they throw no light upon the early history of working iron in England, show the state in which the Art stood at the commencement of the XVIIIth Century; it was at that time, if not in its infancy, in a very imperfect state, and, in all probability, the quantity produced was very small; about fifty years after, the weight of iron manufactured in England amounted to 17,000 tons annually, from which time to the present it has been gradually increasing, till the annual amount, at this time, is nearly 700,000 tons.

Whether any works of this kind had been, in early times, established in Wales does not appear; but these now form a most important portion of the iron works of Great Britain, as will be seen from the following returns, in which is stated the progressive increase of this trade from 1740 to 1827, and the proportional quantity furnished by the different iron works of the Kingdom

Quantities
of iron ma-
nufactured
in different
years.

Anno	Iron made in Great Britain. Tons.	No. of Furnaces.
1740	17,000	59
1788	68,000	85
1796	125,000	121
1806	250,000	
1820	400,000	
1827	690,000	284

By this Table we find that the make of 1827 is prodigiously above any previous year. The following is a statement of the distribution of this quantity in the proportions in which it was produced at the different iron districts.

	Tons.	Furnaces
South Wales.	272,000	90
Staffordshire	216,000	95
Shropshire.	78,000	31
Yorkshire	43,000	24
Scotland.	36,500	18
North Wales.	24,000	12
Derbyshire.	20,500	14

Of this quantity three-tenths is calculated to be foundry iron. This Table shows that the Welsh furnaces are considerably more productive, as to quantity, than those of any other districts; and the difference would, probably, be even greater at the present time, as the average make of the furnaces in Wales has certainly increased since 1827.

At the pre-
sent time.

The following is a list of the quantity of iron sent down from some of the principal works in the Merthyr-district, by the Glamorganshire canal, in 1828. The particulars are supposed to be not all of them perfectly correct, though they are probably not far from the truth. They do not precisely establish the make of the different

Manufac-
tures.

works, as they only, of course, include the iron sent to the shipping port, and can take no account of home consumption, or increase and decrease of stocks at the works.

Cyfarthfa and Hirwin works ;	Tons.
Messrs. Crawshay and Co. . .	25,412
Dowlais ; Guest and Co.	25,020
Plymouth ; Hill and Co.	14,500
Pen y Darran ; Foreman and Co.	10,805
Aberdare	9,262
Gadlys	598
Bute	177
Total	85,774

In 1829, the total quantity sent down the Glamorganshire canal was 88,000 tons; and in 1830 it was rather reduced again, the quantity being 87,364 tons, distributed in the following proportions amongst the different works.

Dowlais	Tons.
Cyfarthfa, &c.	29,621
Pen y Darran	21,312
Plymouth	12,582
Aberdare	13,046
Blakemore and Co.	7,248
Brown and Co.	2,891
	664
Total	87,364

The above works do not comprise half the South Wales district, the shipments from the port of Newport being greater than those from Cardiff. The returns of iron by the Monmouthshire canal to Newport, are for

	Tons.
1829	108,000
1830	106,000

This superiority of traffic on the part of Newport to Cardiff, was by no means the case some years ago, but latterly the works of Monmouthshire have been much increased, and have given a population and an importance to that district that was before unknown. Indeed, the face of nature has been entirely changed in some places in the space of a few years, by the establishment of new works. Romantic valleys, that before were rarely traversed by a human being, are now intersected by rail-roads, and studded with rows of workmen's houses. The flourishing woods that clothed the sides of the hills, and in the winter sheltered innumerable woodcocks, are now cut down for pit timber, or blackened by smoke, which prevents the former tenants from resuming their visits; and the clear mountain streams that teemed with life, and afforded a never-failing resource to the fisherman, are now thickened and poisoned by the mineral waters that drain into them.

The statistical inquirer may perhaps be curious to learn some particulars as to the number of people supported by the manufacture of iron in South Wales. These particulars are not to be obtained with facility, from the circumstance of there being many master workmen, or contractors, at every work, who employ a number of workmen under them, whose names are not returned in the pay books. From the best information that could be obtained on this subject, the following is a statement of the number employed on a work where there are five furnaces, and a forge and mill capable of

manufacturing about two hundred tons of bar iron weekly. Each particular class of labour is here kept separate, and the numbers of women and boys are given as well as that of the men, from which it will be observed that the employment for the former at iron works is not very extensive.

	Men.	Women.	Boys.
Colliers, including road men, horse tenders, and sundry labourers . .	280	0	27
Miners, including stacking and loading the mine, road men, horse tenders, and sundry labourers . .	395	40	73
Furnaces, &c., including furnace labour, viz., keepers, fillers, refiners, cokers, pig weighers, engineers, fitters up, moulders, smiths, carpenters, sawyers, stable men, brick makers, masons, machine men, carriers, &c.	257	39	36
Forge and mill, viz. puddlers, shinglers, rollers, catchers, straighteners, smiths, ballers, engineers, bar weighers, clerks, &c.	145	5	55
Agents, overlookers, and others, not included in the above	31	0	0
Total	1108	84	191

From the above statement it appears that five furnaces, with a corresponding establishment for the manufacture of bar iron, provide *direct* employment for near fourteen hundred individuals. Supposing in round numbers that a work of this size produces a twentieth of the iron made in South Wales and Monmouthshire, which supposition will not be far from the truth, and supposing, likewise, that the number of work people here stated affords a tolerably fair average, the iron works in this district give direct employment to about 28,000 people, to say nothing of the wives and families who derive their support from the labour of the men, and the much larger number who are necessarily employed and maintained in a variety of ways in every populous district.

It will be seen by a reference to the canal returns of bar iron sent to Newport and Cardiff, that a work producing about two hundred tons a week may fairly be stated to form a twentieth of the whole production of South Wales; and this calculation is confirmed by the following Table of the number of furnaces, which shows a proportion of nearly one to twenty in a work consisting of five furnaces compared with the total number.

	No. of Furnaces in blast.	No. of Furnaces out of blast.	Total.
Dowlais Iron-works ; Guest and Co.	9	3	12
Cyfarthfa ; Crawshay and Sons . .	9	0	9
Hirwen	4	0	4
Plymouth ; Hill and Co.	5	2	7
Pen y Darran ; Thompson, Foreman, and Co.	5	0	5
Romney and Bute Works	2	2	4
Sir Howey and Ebbw Vale Works ; Harfords, Davies, and Co.	6	1	7
Nant y Glo ; Bailey, Brothers . . .	7	0	7
Tredeggar ; Thompson, Foreman, and Co.	5	0	5
Aberdare	3	3	6
Abersychan ; British Iron Company	3	2	5
Varteg Hill ; Kenricks and Co. . .	5	0	5
Blaenafon ; Hills and Wheeley . .	4	0	4
Beaufort ; Kendal, Bevan, and Co.	3	1	4

Manufac- tures.	No. of Furnaces in blast.	No. of Furnaces out of blast.	Total.
Clydach; Frere and Co.	3	0	3
The Race; C. H. Leigh	1	2	3
Pentwyn; Hunt, Brothers, and Co.	2	0	2
Coalbrook Vale; Brewers	1	1	2
Blaina; Jones and Co.	2	0	2
Yniscedwm; Crane and Co.	2	0	2
Maestey	2	0	2
Pontrhyd y Ven; Reynolds and Co.	2	0	2
Vigors	2	0	2
Pentyrch; R. Blakemore	1	0	1
Gadlys; Bryant	1	0	1
Ryddry	0	1	1
Cefn Crubm	1	0	1
Total	90	18	18

Coal
mining.

(230.) *History of coal mining.*—The first notice we find of coals being employed by artificers as fuel is by Theophrastus, who describes them as earthy substances which burn like wood-coal, and are used by the smiths. The ancient Britons had a primitive name for this fossil; and Pennant says, "that a flint axe, the instrument of the aborigines of our Island, was discovered in a certain bed of coal in Monmouthshire, so situated as to render the mineral very accessible to the inexperienced natives, who in early times were incapable of pursuing the seams to any great depths."

As to the arguments that have been used to prove that the Romans, while in possession of this Country, were ignorant of the use of this species of fuel, (namely that they had no name for it, *carbo* being always used for charcoal,) we cannot consider it to have very great weight; and we believe all that can be said on the subject is, there is no proof that it was employed by them for the purposes of fuel, and no notice of it by Cæsar in his account of this Island. Some writers, however, maintain that there is great reason to conclude that certain coal mines were worked by the Romans, but their reasoning seems to be equally inconclusive with those who argue on the other side. One of the grounds on which this side of the question is maintained is, that in the West Riding of Yorkshire there are many beds of cinder in which Roman coins have been found, and a statement is made by Horsly, that there is reason to believe a certain colliery at Benwell was actually worked by the Romans, but whatever reason that may be is not stated.

There seems better authority for supposing that the Saxons knew the use of this fuel, but no notice is found any where recorded of it during the usurpation by the Danes, nor indeed for many years after the Norman conquest.

The first Charter for the license of digging coal was granted by Henry III. in the year 1239; it was there denominated sea-coal; and in 1281, Newcastle was famous for its trade in this article; but in 1306, its use was prohibited in London, from its supposed tendency to corrupt the air. However, soon after this it was used as a common fuel in the King's palace in London, and, in 1325, a trade was opened between France and England, in which corn was imported and coals exported. In the year 1379 the first duty of sixpence per ton was imposed upon ships coming from Newcastle with coals. At this period, the inhabitants of the County of Durham had obtained no privilege to load or unload coals on the South side of the Tyne; but in 1384, Richard II., on account of his devotion to Cuthbert, the tutelary saint of Durham, granted them license to export the produce of their mines without paying any duties to the Corporation

of Newcastle; and in the year 1421, it was enacted, Machinery. that the keels or lighters carrying coals to the ships should measure exactly twenty chaldrons, to prevent frauds in the duties payable to the King.

About the middle of the XVth century, Eneas Sylvius, afterwards Pope Pius II., visited this Country; and he remarked, that the poor of Scotland received for alms pieces of stone, which they burnt instead of wood, of which latter fuel the Country was very destitute. The best coals were sold in London about the beginning of the XVIth Century at the rate of four shillings and one penny per chaldron, and at about two shillings and sixpence at Newcastle; in 1563, an Act was passed in Scotland to prevent the exportation of coals, which had been the cause of a great dearth of fuel in that Country. In 1582, Queen Elizabeth obtained a lease of a great part of the mines of Durham for ninety-three years, at the annual rent of £90, which occasioned an advance in the price of coals. This lease was afterwards assigned to Thomas Sutton, the founder of the Charter House in London, who assigned it again to the Corporation of Newcastle, for the sum of £12,000, and the price of coals was immediately advanced to seven and eight shillings per chaldron. But notwithstanding these several advances upon this article, when Queen Elizabeth demanded the arrears of twopence per chaldron, which had been granted to Henry V., but the payment of which had been neglected by the Corporation, they petitioned for a remission of the debt on account of their inability, which was granted, and also a Charter to incorporate a new Company called *hostmen*, or coal-engrossers, for selling all coals to the shipping; in consequence of which the Corporation imposed one shilling per chaldron additional upon this article.

The Lord Mayor of London at this time made a complaint to the Lord Treasurer Burleigh, that the free hosts in Newcastle, to whom, for the use of the town, the grand lease had been assigned, had transferred their rights to a few persons, who engrossed all the other collieries, and he requested that the price of coals should not exceed seven shillings per chaldron, and that these collieries might be free. Up to this time, 1600, it does not appear that any mechanical means, beyond that of manual labour or the employment of horses, had been had recourse to for raising the coals from the pits, which had not yet, perhaps, attained to any considerable depths; but at this date a predecessor of the first Earl of Balcarras invented in Scotland an engine for drawing the water and coals out of the coal mines, and he obtained from James IV. a patent for twenty-one years; but this improvement was not till some time after adopted in the neighbourhood of Newcastle. In a petition of grievances, presented by the House of Commons to King James in 1610, a complaint occurred of a late imposition of one shilling per chaldron on sea coal, raised in Blyth and Sunderland, not by virtue of any contract or grant, as on the coals of Newcastle, but under the mere pretext, assumed by the contractors, of his Majesty's Royal prerogative. This petition displayed so strongly the rapacity of that body of men, and the distress occasioned by it to the inhabitants of London, that the prayer of the petition was immediately complied with; and an information was exhibited in the Star Chamber, during the same reign, by the Attorney-General, against the Mayor and Burgesses of Newcastle, by the name of *hostmen*; for that they, having the preemption of coals for the inheritors in Northumberland and the County of Durham, by their Charter of the 42d of Elizabeth, forced ships to

Manufac-
tures.

take bad coals, amongst which was a quantity of slate; for this they were fined to the amount of one hundred pounds each, and committed to the Fleet prison: the decree, moreover, was ordered to be read in the open market in Newcastle on two several market days.

In 1615, four hundred sail of ships were employed in the coal trade of Newcastle, one half of which supplied London, and the rest the other part of the Kingdom; the French traded to Newcastle at this time for their coals in fleets of fifty sail at a time, serving the ports of Picardy, Normandy, Bretagne, and as far as Rochelle and Bourdeaux; while the ships of Bremen, Embden, Holland, and Zealand were supplying the inhabitants of Flanders.

About the year 1625, another patent for raising water and coal from the mines was granted to one David Ramsay, but the particulars of it are not described, and at this time wooden railways begun to come into use, for transferring the coals from the pits to the staiths, where they were put on shipboard.

From this time to near the middle of the following century we find but little information relative to any new mechanical assistance given to the miner; this whole period of nearly one hundred years being only prolific in producing various impositions of duty by the Government, and of unauthorized demands by the Mayor, Corporation, hostmen, and others; of prosecutions, fines, imprisonments, &c.; circumstances of but little interest at this time, and, therefore, a simple statement of a few of the more prominent facts will be sufficient.

In 1630 a duty of five shillings per chaldron was enforced for all coals for exportation; and a further sum of one shilling and eightpence, if the exportation was effected by any Englishman.

In 1634, the above duty appears to have been repealed, and a duty of four shillings per chaldron laid on coals exported to foreign ports.

In 1637, an impost of one shilling per chaldron was laid by the Mayor and Corporation of Newcastle on the vend of coals for exportation.

In 1667, coals were sold in London at thirty shillings per chaldron, and an Act or order of Parliament was made at this time, prohibiting their being sold at a higher price before March 25, 1768.

This year, in consequence of the fire in London, one shilling per chaldron, on coals entering the Thames, was granted to the Corporation of London, as an aid for rebuilding the several Churches which had been destroyed. This was afterwards raised to three shillings per chaldron, to continue for twenty years.

The same year, also, Charles II. granted to his illegitimate son, the Duke of Richmond, a duty of one shilling per Newcastle chaldron, on all coals passing coastwise from Newcastle, which he and his successors levied till the year 1800, when the Government bought the right of the then Duke for an annuity which was afterwards compounded for by the present sum of £400,000 sterling.

At the end of the XVIIth Century 1400 ships are said to have been employed in exporting yearly from Newcastle 200,000 chaldrons of coals, Newcastle measure: each Newcastle chaldron amounting to about two London chaldron; its weight being fifty-three hundred-weight.

It would be uninteresting to pursue this subject through all the fluctuations and changes of imposts which followed between this period and the commence-

ment of the XIXth Century, at which time, or soon after, the Government duty per London chaldron in the port of London was nine shillings and fourpence; but in 1824 a reduction of three shillings and fourpence took place; and finally, in 1830, the remaining duty of six shillings.

(231.) To show the gradual increase in the price of coals, from the middle of the last century in Newcastle and in London, we make the following abstract from the Report of a Committee of the House of Commons, appointed to examine into the state of the coal trade in 1830, from which it appears that

At Newcastle the average price per London chaldron was in

	£.	s.	d.
1771	0	6	9
1794	0	9	6
1800	0	11	0
1828	0	14	0

And in London the average selling price per chaldron was in

	£.	s.	d.
1788	1	10	4 $\frac{3}{4}$
1790	1	12	9 $\frac{1}{4}$
1792	1	10	9
1793	1	15	0 $\frac{3}{4}$
1795	2	1	10 $\frac{1}{2}$
1797	1	15	2 $\frac{1}{2}$
1799	2	2	0 $\frac{3}{4}$
1800	2	12	3 $\frac{1}{2}$

These being the prices in the Pool, independent of any expense subsequent to their arrival.

And the charges to which every chaldron of coal was liable, after the reduction of duty in 1824, is thus stated in the same report for coals brought from the rivers Tyne and Wear.

Particulars of the Charge of One Imperial Chaldron of a Cargo of Coals from the Tyne delivered in London, sold at £35 per Score of Twenty-one Chaldrons, with 8d. Metage, and 1d. Market Dues per Chaldron. Measured out 222 $\frac{1}{4}$ Chaldrons.

	s.	d.	s.	d.	£.	s.	d.
Paid to coal owners for the best coals, including metage	15	0					
Spoutage on ditto	0	3					

Charges at Newcastle.

Coast or Richmond duty, per Newcastle chaldron 1s. 0d.	per Imperial Chaldron.	0 6
Town dues to Corporation of Newcastle		
0 2		0 1
		15 10

Charges in London.

Lord Mayor's dues and groundage	0	0 $\frac{1}{2}$
Market dues	0	1
Meters 4d., Orphan fund	1	2
King's duty	6	0
Discount on scorage to buyers	0	6 $\frac{1}{4}$
Factorage	0	4 $\frac{1}{4}$
Entry, stamps, fees, &c.	0	2 $\frac{1}{2}$
		1 4 2 $\frac{1}{4}$
Insurance on cargo, at 20s. per cent. and policy	0	0 2
Loss on ingrain by being paid for 20 chaldrons, all the expenses being on 21	0	1 8
Freight	0	9 8 $\frac{1}{4}$
		1 15 9

	£.	s.	d.
The buyer pays for one chaldron	1	14	1
Loss to the seller for ingrain	0	1	8
			1 15 9

Machinery.

Price of
coals in
London.

Manufactures.

Particulars of the Charges on one Imperial Chaldron of a Cargo of Coals (from the Wear) delivered in London, sold at £35 per Score of Twenty-one Chaldrons, with 8d. Metage and 1d. Market Dues per Chaldron. Measured out 222½ Chaldrons Imperial Measure.

	s.	d.	£.	s.	d.
Paid the coal owner for coals, including metage.....	0	16	3		
<i>Charges in London.</i>					
Lord Mayor's dues and groundage	0	0	½		
Market dues.....	0	1			
Metage 4d., and Orphan dues 10d.....	1	2			
King's duty	6	0			
Discount on scoreage to buyers	0	6	½		
Factorage	0	4	½		
Entries, stamps, fees, &c.....	0	2	½		
	0	8	4	½	
	1	4	7	½	
Insurance on cargo at 20s. per cent., policy, &c.....	0	0	2		
Loss on ingrain, by being paid for 20 chaldrons, all the expenses being on 21.....	0	1	8		
Freight	0	9	3	½	
	1	15	9		
The buyer pays for one chaldron as above	1	14	1		
Loss to seller for ingrain	0	1	8		
	1	15	9		

After these charges on the coals in the Pool, they are subject still to the following further expense for whippers, who take the coals from the vessel, (see Art. 6.) and for meters and meters' men, &c.: these charges are thus stated:

	£.	s.	d.
For every score of 21 chaldrons the ship meter receives	0	3	6
Ditto for food per day	0	3	0
In lieu of sample (per ship)	1	1	0
These payments are made by the ship,—			
A payment to City of London per chaldron	0	1	
A payment to Custom House	0	0	½
and 3d. additional for each certificate made out			

It further appears that, in 1829, in which year there had arrived in the Pool 7021 ships with coals bearing 1,503,581 chaldrons,

	£.	s.	d.
The meters received	33,690	19	4
Meters' men at 3s. per score chaldron .	11,951	17	0
Nine whippers, each ditto.....	107,566	13	0

Many of these dues, and certain restrictions with which the trade was embarrassed, have been however removed, as also the duty of six shillings per chaldron, whereby the commerce in this important article has been rendered more free, more cheap to the consumer, and not less profitable to the mine proprietor.

Having above stated such particulars as appeared deserving of notice recording the charges on coals, the different imposts and restrictions to which the trade was subject, but the greater number of which are now judiciously removed, it will be well to show the increase which has for several years been observed in the consumption of this article in the Metropolis. This will be seen in the following Table.

TABLE showing the Import of Coals for each Year, Machinery. during Twenty-eight Years, commencing 1801; also the mean Annual Rate of Increase, and the Population of the Metropolis at three different Periods.

Years.	Chaldrons of Coals Imported.	Population by Census.	Population by Estimation.	Chaldrons per Head.
1801	859,738	818,129	..	1.05
1802	902,284	..	831,628	1.06
1803	940,470	..	845,127	1.07
1804	947,001	..	858,626	1.07
1805	974,314	..	872,125	1.08
1806	987,750	..	885,624	1.09
1807	933,148	..	899,123	1.09
1808	1,088,010	..	912,622	1.105
1809	923,440	..	926,121	1.112
1810	1,120,237	..	939,620	1.118
1811	1,115,171	953,276	..	1.12
1812	1,071,361	..	972,184	1.125
1813	970,898	..	991,249	1.125
1814	1,140,168	..	1,010,314	1.124
1815	1,117,034	..	1,029,379	1.08
1816	1,214,405	..	1,048,444	1.09
1817	1,137,891	..	1,067,509	1.107
1818	1,202,541	..	1,086,574	1.118
1819	1,179,544	..	1,105,639	1.127
1820	1,313,736	..	1,124,704	1.18
1821	1,270,270	..	..	1.146
1822	1,253,705	1,144,531	1,163,596	1.156
1823	1,425,662	..	1,182,661	
1824	1,505,021	..	1,201,726	
1825	1,410,120	..	1,220,791	
1826	1,581,974	..	1,239,856	
1827	1,453,747	..	1,258,921	
1828	1,540,875	..	1,277,986	

Amount of coal consumed in London.

The numbers in the last column are not computed from the actual import, but from an assumed equalized consumption for each ten years.

An Account of the Quantity of Coals vended from the River Tyne and the Port of Sunderland, from the Year 1800 to 1828, in Newcastle Chaldrons of 53 Hundred-weight.

River Tyne.			Port of Sunderland.		
Year.	Coastwise.	Foreign.	Coastwise.	Foreign.	Year.
1800	537,793	47,487	298,837	4,622½	1800
1801	452,192	50,401	231,018	475½	1801
1802	494,488	44,300	305,07½	31,205½	1802
1803	505,137	44,324	298,946	10,167	1803
1804	579,929	52,589	299,552	4,162	1804
1805	552,827	49,572	313,307	5,955½	1805
1806	588,277	46,683	306,271	2,613	1806
1807	529,950	27,424	290,938½	4,276	1807
1808	619,125	16,001	348,623	2,058½	1808
1809	539,098	13,639	324,130	937½	1809
1810	632,299	17,253	370,712½	1,919½	1810
1811	633,359	17,954	330,942	1,929½	1811
1812	630,633	24,985	338,854½	3,148½	1812
1813	584,184	14,761	347,150	1,779½	1813
1814	649,151	31,986	373,241½	11,029½	1814

Manufactures.

TABLE continued.

River Tyne.			Port of Sunderland.		
Year.	Coastwise.	Foreign.	Coastwise.	Foreign.	Year.
1815	650,209	42,434	337,903	16,989	1815
1816	678,151	43,783	387,687½	15,930½	1816
1817	622,977	51,797	363,868	11,627	1817
1818	671,871	47,744	391,790½	15,839	1818
1819	639,987	39,735	378,445½	15,471½	1819
1820	756,513	44,826	415,972½	14,425½	1820
1821	692,321	48,097	396,205	14,575	1821
1822	655,159	54,160	396,921	16,418½	1822
1823	738,909	46,725	497,126½	15,546½	1823
1824	687,603	49,044	491,187	15,880	1824
1825	787,029	51,344	521,796	15,531	1825
1826	792,365	62,620	545,656	14,498	1826
1827	683,745	65,417	523,437½	14,953	1827
1828	725,082	69,325	509,467½	22,941	1828

The above only show the quantities shipped at the two places stated, but the following return shows the quantities of coals, small coals, culm, and cinders, exported from the different ports of England, Scotland, and Wales for each year, from 1819 to 1828.

Amount of coal, culm, &c. exported from different ports.

Years.	Coals and Cinders.		Small Coals.		Culm.		Total in Tons.
	Tons.	Newcastle Chaldron.	Imperial Chaldron.	Newcastle Chaldron.	Imperial Chaldron.	Newcastle Chaldron.	
1819	613,996	22,732	2,502,997	35,712	1,372	9	4,365,040
1820	572,955	20,536	2,819,506	36,509	1,855	159	4,803,427
1821	623,582	23,617	2,664,788	57,509	2,121	218	4,638,059
1822	666,763	22,425	2,733,534	38,892	19,146	216	4,788,839
1823	720,018	16,579	3,097,070	42,599	3,622	526	5,319,627
1824	733,980	18,783	3,015,949	44,349	4,523	515	5,279,192
1825	737,837	15,501	3,061,817	47,671	32,426	755	5,391,763
1826	881,415	9,222	3,211,205	57,565	81,673	270	5,856,547
1827	892,188	11,403	2,899,805	59,867	106,240	478	5,458,377
1828	977,485	11,056	2,976,093	60,315	78,041	26	5,603,807

This extraordinary export of coal is of course wholly independent of the inland consumption, of which latter, perhaps, not less than 3,000,000 tons are employed in our iron works only, besides numerous other works. Including therefore these, and private inland consumption, we have no reason to doubt the probable accuracy of the estimate stated by Mr. Taylor, in his evidence before the Committee of the House of Lords, *i. e.* that the whole consumption of coal in Great Britain amounted to the enormous quantity of 19,540,000 tons annually, exclusive of foreign exportation.

This estimate is made out as follows:

	Tons.
The annual sale of coals carried coastwise from Durham and Northumberland	3,300,000
Home consumption one-fifth	660,000
Total	3,960,000
This quantity supplies about 5,000,000 persons, which, supposing the whole population 15 millions, must be tripled	11,880,000
Consumed in iron works, and in mines of Cornwall	3,000,000
Total consumed in Great Britain	14,880,000
Exported to Ireland	700,000
Total United Kingdom	15,580,000

(232.) This extraordinary annual consumption naturally led to inquiries by the Committee, of the present extent of unworked coal in the Kingdom, and the probable time they may last, supposing the present demand to remain constant. Mr. Taylor stated, that he computed the time requisite to exhaust the supplies furnished by the Durham and Northumberland district exceeded 1700 years; but this estimate was considered by Professor Sedgwick and Dr. Buckland to be very much overrated, many of the parts included in Mr. Taylor's map being, as stated by them, wholly barren of coal, and in other parts of it there was not sufficient evidence of coals existing. Dr. Buckland being asked if he was aware of the waste of coals arising from the regulations established at the mines, and whether the extent of our unworked coal was such as to render such waste unimportant in a national point of view, replied, "that he had always considered such waste as a national calamity; it appeared to him (the witness) that we were wasting unnecessarily, that which it was the duty of the nation to preserve for the use of posterity." Dr. Buckland being afterwards referred to the following extract from Mr. Bakewell's *Geology*, in which the time the Durham and Northumberland coals will last is estimated at only 360 years, was asked if he thought the period underrated. He replied, "he did, and that he should rather be disposed to say that 400 years is a more probable estimate." The quotation in question is as follows.

"We cannot but regard the exhaustion of our coal beds, as involving the destruction of a great portion of our private comfort and national prosperity, nor is the period very remote when the coal districts, which at present supply the metropolis with fuel, will cease to yield any more. The number and extent of all the principal coal beds in Northumberland and Durham is known, and from these data it has been calculated that the coal in these Counties will last 360 years. Mr. Baily, in his survey of Durham, states that one-third of

Machinery
Annual consumption in Great Britain.

Probable time the coals of England may last.

Manufactures.

Machinery.

the coal has been already got, and that the coal district will be exhausted in 200 years. It is probable that many beds of inferior coals, which are now neglected, may in future be worked, but the consumption being greatly increased since Mr. Bailey published his survey of Durham we may admit his calculation to be an approximation to the truth, and that the coals of Durham and Northumberland will be exhausted in a period little exceeding what is above stated." Dr. Thomson, in the *Annals of Philosophy*, has calculated that the coal of these districts, at the rate of consumption going on when he wrote his Paper, will last 1000 years; but his calculation Mr. Bakewell considers to be manifestly erroneous, and, correcting certain errors which he points out, he concludes that Dr. Thomson's own estimate must be reduced, according to his own showing, to 360 years.

It cannot, Mr. Blakely observes, be deemed uninteresting to inquire what are the repositories that can supply the metropolis and the Southern Counties with fuel when no more can be obtained from the Tyne and the Wear. The only coal fields of any extent, on the Eastern side of England, between London and Durham, are those of Derbyshire and those in the West Riding of Yorkshire. The Derbyshire coal field is not of sufficient magnitude to supply, for any long period, more than is required for home consumption and that of the adjacent Counties. There are, however, many valuable beds of coal in the Western part of the West Riding of Yorkshire which are yet unwrought, but the time, Mr. Bakewell thinks, is not far distant, when they must be put in requisition to supply the vast demand of that populous manufacturing district, which at present consumes nearly the whole produce of its own open mines. In the Midland Counties, Staffordshire possesses the nearest coal district to the metropolis of any great extent, but such is the immense daily consumption in the iron furnaces and founderies, that it is generally believed, according to this author, this will be the first of our English coal fields that will be exhausted; and of the coals of Lancashire he reckons very little, so that, upon the whole, his estimate of the time of duration of the coal and ironstone of England is far from promising. On the other hand, by adopting the extent of the coal mines of Wales from the survey of Martin, he runs into the opposite extreme in respect to the coal of that district, estimating it to be adequate to supply all demands for 2000 years after the English coals are exhausted. Here, however, he falls into precisely the error he accuses Dr. Thomson of, in Durham and Northumberland, that is, accounting upon a thickness exceeding what can be made available, and not allowing for points where the coals crop out. The most correct view, in all probability, of the extent of coals in this district, is contained in a letter from Rev. Mr. Conybeare to Mr. Warburton, published in the Report to which we have so often referred. The coal measures, according to Mr. Conybeare's statement, do not lie horizontally within the limestone basin as assumed by Martin, but in a trough shape, being deepest towards the middle, and rising upwards towards the upper limits; the ends of the several seams *cropping out*, as the miners term it, that is, appearing successively at the surface. They do not, however, form one uniform sweep or inverted arch, but present a section resembling that shown in fig. 3, pl. xvi.

There are thus two basins, the one lying to the North, the other to the South of a high ridge, which runs from

Aberavon, half a mile North of the Avon, by Cefn Eglwysillan, two or three miles North of Caerphilly, a little beyond which it disappears. In the Northern basin, which is by far the most extensive, the strata are much less inclined than in the Southern basin; for in the former the dip of the strata is generally under 10° , while in the latter it is often 45° and upwards. The whole coal field is traversed by *dykes* or *faults*, generally in a North and South direction, which throw all the strata from 300 to 600 feet up or down. On the Western termination of the basin, in St. Bride's Bay, the strata exhibit the most extraordinary marks of confusion and derangement, being vertical and twisted in every possible direction.

The extent of this coal field, and the thickness of the seams, have been variously stated by different authors; but the estimate which is perhaps the most to be relied upon, is Mr. Conybeare's, who makes three great divisions of the coal seams, the lower, middle, and upper series; and he assigns to them, respectively, the average thicknesses of thirty-five, fifteen, and ten feet, making altogether sixty feet of workable coal. Martin, who described this coal field, makes them amount to ninety-five feet; and Mr. Conybeare thinks that Martin does not overstate the amount, provided all the seams be taken into the account. But Mr. Conybeare's calculation only includes the workable coals, and he considers that those seams cannot be worked with profit where it is necessary to go lower than 200 fathoms, or 1200 feet, for beyond this the expense of drainage, &c., becomes enormous. Keeping the same considerations in view, Mr. Conybeare makes the following estimate of the area occupied by the coal seams:

For the lower series, 525 square miles, at 35 feet thick.

"	"	100	"	17	"
"	middle series,	360	"	16	"
"	upper series,	64	"	10	"

This, it is calculated, after deducting one-half for loss and for what has been already worked, will amount to about 11,423,750,000 tons; and taking the annual consumption of all England at 15,000,000 of tons, the provision of good coal in the South Wales basin is sufficient for 760 years. This, with the 400 years agreed to, as the probable duration of the Durham and Northumberland coals, both by Professor Sedgwick and Dr. Buckland, gives a period of nearly 1200 years, and adding all other English sources, there can be little doubt of an abundant supply for 2000 years.

Moreover, we have hitherto spoken only of the coal fields of England and Wales, and have taken no notice of the large deposits which exist in Scotland. Nearly all the valuable mines in that Country are in the Lowlands, between the Highlands on the North and the range of slate mountains which run in a North-East and South-West direction across the island, in the South of Scotland. The Capital is very abundantly supplied with excellent qualities of coal brought from a distance of only a few miles, and delivered in Edinburgh at from nine to twelve shillings per ton. Glasgow is surrounded with collieries, and is supplied at even a cheaper rate than the Capital; and to this profusion of fuel not only Glasgow but Paisley, and the neighbouring manufacturing towns, owe, in a great degree, their origin and prosperity. The mines in the Counties of Fife and Clackmannan also produce very fine qualities of coal.

The coal formation of Scotland is found in the County of Antrim, on the opposite coast of Ireland. The col-

Manufactures.

Discovery of an old coal mine in Ireland.

Numerous coal fields in Ireland.

lieries of Ballycastle, on the North coast of Antrim, were formerly considerable, sending from ten to fifteen thousand tons to market yearly; but they are now greatly fallen off.

(233.) A very extraordinary discovery was made at these collieries about the year 1770: the miners unexpectedly discovered a passage cut through the rock, which was very narrow, owing to incrustations formed on its sides; but, on being sufficiently widened, some workmen went through it, and found that it led to a gallery which had been driven forward many hundred yards into the bed of coal. It branched out into thirty-six chambers, where the coal had been worked out in a regular manner, pillars being left at proper intervals to support the roof. Some remains of the tools, and even of the baskets, used in the works, were discovered, but in such a decayed state that, on being touched, they fell to pieces. There does not exist the most remote tradition of such a work in the Country; and its great antiquity is proved by the sparry incrustations on the sides and pillars of the mine, for, in such a situation, a very long period would probably elapse before these would be deposited. (See Hamilton's Letters on Antrim.) In the Eastern part of the County of Tyrone, at Coal Island and Dungannon, a coal formation occurs associated with that variety of limestone which is usually found underlying or alternating with the coal measures in Scotland and England.

(234.) But coal has been discovered in greater or less quantity in seventeen Counties of Ireland. The coal district of the Province of Munster, according to Mr. Richard Griffith, an experienced Geologist and practical engineer, is greater in extent than any in England, and probably contains, he says, almost inexhaustible beds of coal. It extends over a part of the County of Clare, over a considerable portion of the Counties of Limerick and Kerry, and a large part of the County of Cork. But the quality of the coal is quite different from either the English or Scotch coal, being that variety called anthracite, which burns without flame, and approaches to the nature of charcoal. It is chiefly used for burning the limestone in the adjoining districts; and the most considerable collieries, those of Dromagh, have yielded 25,000 tons per annum, at from ten to fifteen shillings per ton. The district of Clare belongs to the true coal measures, but they are chiefly the shales, sandstones, and sandy slates, coal being of very rare occurrence, as far as discoveries have yet been made, and when found it is of very indifferent quality. Mr. Griffith is of opinion that coal of a bituminous quality is very extensively distributed over the Eastern part of the Province of Connaught, particularly in the Counties of Leitrim and Roscommon; but little is as yet known with respect to the number and thickness of the seams, or the facility of working them. In the Province of Ulster, besides the collieries in the Counties of Antrim and Tyrone already mentioned, coal has been met with in the Counties of Fermanagh, Monaghan, and Cavan, but not to any great extent. The Province of Leinster contains the true coal measures, lying above the carboniferous limestone, in the County of Carlow, and in Queen's County, and in the County of Kilkenny, from whence it stretches some way into the County of Tipperary. The great deposits are around Castlecomer in Kilkenny, and Killenaule in Tipperary, and both these have been extensively worked; but according to Mr. Weaver, in his account of the Killenaule district, the coal, not only of that field, but that of the other portions

of the Leinster coal tract, is wholly of the nature of anthracite, and of a thin stratified structure.

With the prospect held out in the preceding estimates of the continuance of a supply of fuel for future years, we can have nothing to apprehend, at the same time unnecessary waste ought to be avoided, and it is expected this will be effected by the late regulations.

We now proceed to describe the working of the coals in the vicinity of Newcastle, in which we shall again avail ourselves of the very able evidence of Mr. Buddle in the Lords' Committee already referred to.

(235.) *Methods of working coals.*—When a certain tract or field of coals is to be opened, the operation is known in the coal districts by the term *winning a colliery*. The process being of course first to form a shaft, a work frequently attended with great labour and expense, at the same time that the value of the colliery, after it is won, is so doubtful, that the business is generally undertaken by a Company, who engage the colliery on lease of the proprietor, so that in case of failure, the loss being distributed, is not so severely felt, as it would be if undertaken by the proprietor himself, or any other single individual. In sinking the shaft it frequently happens water is met with in such quantities that cast-iron caissons become necessary. Mr. Buddle, in his evidence, says: One of the difficulties in sinking a shaft is passing through quicksands; another is the immense quantity of water which is met with in certain parts of the stratification, generally within forty or fifty fathoms of the surface, which has always to be dammed back by what is technically called a *tub*, that is, by the cast-iron caisson above mentioned.

In one shaft, particularly described, and which is shown in pl. xvii. fig. 3, forty feet of this cast-iron tubing was made use of, after which the ground became perfectly impervious to water. Accidents frequently occur also by the breaking of one of these caissons, in which case the water rushes down into the mine, if it be already formed, and drowns it. This of course causes a suspension of operations, and a great loss to the proprietor, till the tub can be repaired; such an accident, while only sinking, is not attended with such serious consequences, although it must necessarily, even in this case, be a great impediment. The quantity of water which thus forces itself into a shaft is such as requires a steam engine of perhaps one hundred and fifty horse power to be erected, in order to counteract this effect only. Mr. Buddle, in one part of his evidence, stated that, to sink only through one fathom of a shaft, he has known it to be requisite to erect an engine of the above power; and no sooner was this small distance passed, and the water well dammed back behind the tub, than the shaft has become comparatively dry: in such cases the expenses of a single fathom sinking may amount to a sum of £4000, while the expense of another fathom in the same shaft will not exceed, for mere workmanship, a sum of above £10. These shafts are of course carried to various depths, according to circumstances; while, as we have seen in some Countries, they are wholly unnecessary. In the neighbourhood of Newcastle the deepest working pit is one hundred and eighty fathoms, but some do not exceed twenty-three or twenty-four fathoms, but these generally yield very inferior coals. It must not, however, be understood, in stating that the deepest of these shafts do not exceed one hundred and eighty fathoms, that the coals are not

Machinery

Operation of sinking a shaft.

Pl. xvii. Fig. 3.

Manufactures. worked to a greater depth, for frequently the miners descend by inclined planes some considerable depth below the bottom of the shaft.

Ventilation. (236.) *Modes of ventilation.*—All the labour of sinking being completed, the miner now begins his work; this is done by first digging and undermining with his pickaxe at the bottom and one side into the seam or stratum of coal, as far as he can, and he then forces down great pieces by a wedge and mallet, leaving at proper intervals pillars to support the superstratum.

Before working can be commenced, however, provision must be made for ventilating the work. This is done by dividing the shaft into two by a boarded partition from top to bottom, one of the two forming the pumping shaft, and the other the coal shaft: on the coal shaft division at the bottom, or suspended in some part in an iron frame, a fire is lighted, which produces a rarefaction on that side, and consequently a draught through the pumping shaft, through the heading and up the coal shaft; but when these headings have been sufficiently extended, a second shaft is sunk, and then the ventilation is carried on by means of the two shafts, after the manner represented in fig. 11. pl. xviii. where the air is supposed to enter the shaft *a*, to be directed through the several galleries, as shown by the arrows, and finally pass up the other shaft at *b*, the direction of the current being ensured in single or double coursings by means of the partitions erected across some of the passages: these partitions are represented by the narrow dotted lines in the figure. The same figure also illustrates the new modes of working referred to by Mr. Buddle in his evidence above reported.

Different methods of working. (237.) Formerly all these pillars were left, and no greater portion of the bed was extracted than is represented by the light spaces, *viz.* about forty per cent.; but in 1795, when several collieries were nearly exhausted, according to this mode of working, attempts were made at partial working by removing one half of every alternate pillar, as shown in lower division of the figure: in this way from fifty to sixty per cent. of all the coal was extracted, and the rest was totally abandoned. These pillars, so remaining, being found to be sufficient to sustain only a roof of twenty, thirty, or forty acres, at which extent the bottom began to yield.

In 1810, another improved system was introduced. The coal mines were exhausting so fast that an attempt was made to remove every alternate pillar, and also a portion of the adjoining ones, as in the upper part of the figure; by that plan, and working in small divisions, about eighty per cent. was obtained: but an ultimate effect in these cases took place, technically denoted a *creep*, which it will be proper now to illustrate.

When the pillars first left to support the roof are lessened too much, in the way above described, a circumstance takes place we should not *à priori* expect, which is, that the foot of the pillars penetrate into the *pavement*, as it is called, or the floor of the gallery, and a slight rising is observed in the middle between two rows of pillars. This continues to increase till it arrives at a second stage, when the pavement begins to open in cracks longitudinally. In the third stage, the crack is completed, and the edges assume a sharp distinct form called metal edges. In the fourth, these metal edges, which continually rise, reach the roof. In the fifth, the edges become flattened against the roof, when the coals begin to take part of the pressure. And the last is when every thing is dead settled, and the

whole space previously excavated becomes again filled by this rising of the pavement. These several stages of the creep are shown in fig. 2, 3, 4, 5, &c.

(238.) Here all attempts at obtaining more coal must have been stopped, but for the invention of the safety lamp by Sir H. Davy, in consequence of the great danger of explosion, and the difficulty of keeping a sufficient light in such situations by the old process of the flint mill; but with the safety lamp, Mr. Buddle states, that the whole of the coals may be obtained. In the plate referred to, this ultimate process is represented. Fig. 8 shows the crushed pillars in the form last described; fig. 9 the first process of digging through the rubbish and a portion of the pillars, the exfoliation of the roof being prevented by props of timber. After going a certain length the whole of the coal is extracted, and then the roof rests for a while on the pillars formed by the flattened ridges of the creep, after which it breaks down, when all the space that had been occupied by the seam of coals is completely filled, either by the creep ridges, or by the falling down of the roof. The following figure represents the exhaustion of the whole district of its coals. A breaking down of the roof, generally extending to the surface, takes place, and the whole is closed. This is the most complete system of working, because if the coals will pay for it, they may be all obtained.

It is not necessary to enter here into any particular detail relative to the pumping of the water and raising the coals, the principle of these operations being nearly the same as in the mines already described. The principal difference is, that the coals having reached the surface, are placed in waggons, and in some instances are brought up in the waggons, and are immediately placed on a railway, and conducted to the staith to be put on shipboard; whereas the ores are left near the pit's mouth to undergo subsequent processes.

(239.) Notwithstanding the precautions taken to ventilate the mines, and the aid afforded by the safety lamp, many serious and afflicting accidents of this kind occur. On this subject Mr. Buddle was examined at some length, and we cannot do better than state his reply, as nearly as possible, in his own words. "One of the great difficulties and cause of expense and uncertainty," he observes, "to which the collieries in the above district are subject is explosion, which is common to collieries both in an open state and in a state of creep, but more particularly in working the latter, where the means of ventilation cannot be so perfect as it is in working a mine in a virgin state. These explosions are occasioned by the firing of inflammable air, either by unavoidable accidents or by the carelessness of the workmen. The inflammable air is evolved from the coal at the natural temperature of the earth, and the coals lying deep abound more in it than those lying near the surface, because there are openings at the surface by which it escapes; but in the deep mines it has no such outlets, and it accordingly accumulates in all the fissures of the stone above the coal, and a sort of natural distillation is thus constantly going on; and, consequently, if the mine is ever so well ventilated and cleared one day, it will be like a well filling with water, become charged with inflammable air the next day, or in a very short time, unless the ventilation is regularly going on." This Mr. Buddle considers the regular generation of the gas; but it is the accumulations of it which are the most dangerous. The fissures of the rock in some places are

Machinery
Pl. xviii.
Fig. 1, 2, 3,
&c.

Explosions
in coal
mines.

Manufac-
tures.

very extensive, and the communications are very distant and remote; these may be considered as natural gasometers out of which the gas, not having any outlet, is compressed by the process of distillation going on from the coal to an extent that is almost incredible; its resistance being, according to the witness, proportional to the extent of rock above it, and the thickness of the surrounding stratification, whatever it may be, stone or coal. In the course of pursuing the working of collieries into the whole coal, the miners frequently cut across the fissures, which are in the roof or in advance, full of inflammable air in a highly compressed state; and these frequently before they are closely approached break away the coal or the stone when it becomes too weak to resist, and in a very short time, even in a few minutes, from a state of apparent perfect safety, a pit becomes completely charged to the point of explosion from the immense quantity of gas rushing from these fissures, which are thereby technically called blowers; and a precisely similar effect takes place in breaking into old works; and in both cases the discharge of gas entirely overpowers the ventilation. If the proportion of gas to atmosphere is as one to fourteen, and does not exceed it, the mixture is not inflammable; but if the proportion is greater than this, the mixture becomes explosive at the first naked light it meets with. The quantities of gas discharged on these occasions cannot be estimated; but Mr. Buddle states, that in one mine in which he was viewer, it required a constant supply of 18,000 cubic feet of air per minute to preserve it in a safe working state, in consequence of the natural production of the gas only, without any reference to such cases as those above related.

In a Paper which this gentleman presented to the Philosophical Society of Newcastle, he has examined into the cause of a serious accident which occurred a few years back at the Jarrow colliery, on an occasion of the kind described above. In this case the seam of coals was broken by what is called a down-cast hitch, and before the working had quite arrived at this place an explosion took place by a piece of coal, as represented in fig. 5, being blown out by the expansive power of the gas. Here the gas was contained in the dirty, disintegrated coal between the two seams; the block of coals, five feet high, nine feet wide, and four feet thick, was thrown to a considerable distance, an explosion took place, and many lives were lost by the accident.

Steel mill.

(240.) *Obtaining light in mines.*—We have hitherto but slightly alluded to the safety lamp, but it will be proper before closing this Division, to offer a few remarks on this important instrument, and the successive steps by which it has attained its present improved form and principle of action. In the progress of mining, in cases in which it was dangerous to carry an open light, recourse was had to the steel mill, so constructed as to produce light by the collision of flint and steel. It consisted of a brass wheel about five inches in diameter, with fifty-two teeth which worked a pinion of eleven teeth. On the pinion was fitted a thin jagged steel wheel from five to six inches in diameter. Against the circumference of this wheel the sharp edge of a flint was fixed, and the tooth wheel had a handle which was turned by a boy, the whole frame having been fixed in an iron frame suspended by a leathern belt; such was the original form of this rude instrument, and such, we believe, it still continues, although it is now but seldom had recourse to. When it is used, the steel wheel is made to revolve with great velocity which thus elicits a

stream of scintillations which give a considerable light, but is of course unsteady and inconvenient; yet Mr. Buddle states in his evidence before referred to, that, prior to the year 1809, it was not unusual for him to be obliged to write and conduct much of his business underground by aid of the light thus produced.

(241.) About 1813, (see *Phil. Trans.* for that year,) Dr. Clanny, a scientific physician of Sunderland, commenced a series of experiments with a view of insulating the gas which might explode in a lamp, and thus to cut off its communication with the surrounding air in the mine. With this intent he constructed a lamp in which the combustion of the oil or tallow is supported by the ordinary air of the coal mine supplied by a pair of bellows, and passing through a stratum or reservoir of water below the light, at the same time a portion of the air already in the lamp is driven through another reservoir in the upper part above the light; and thus the air supplied may explode within the body of the lamp, without communicating the flame to the external air, however highly it may be charged with carburetted hydrogen gas. The moment the air enters the lamp it comes in contact with the flame, and consequently only a small portion of it can explode instead of the whole content of the lamp, by which means several obvious advantages are secured. The air passing by a quick current close by the flame carries the snuff with it, so that the light is always clear and steady. The other parts are air tight, and the whole is made very strong, defended by thick glass to prevent its being broken by common accident, and it was as much within the management of a boy as the old steel mill. It was, however, by no means generally introduced; hundreds of lives were sacrificed; the evil from explosion remaining almost wholly unabated. At length a Society being formed in 1813, with a view to preventing accidents in mines, Dr. Gray, Rector of Bishop Wearmouth, now Bishop of Bristol, and an active partisan in the cause, consulted Sir H. Davy on the subject; and this led to the highly important invention of the safety lamp as at present employed, and to which reference has been made in the preceding articles.

(242.) This invention, see pl. xvi. fig. 6, consists in surrounding the flame of a lamp or candle by a wire sieve. The coarsest that he tried with perfect safety contained six hundred and twenty-five apertures in a square inch, and the wire was one-seventieth of an inch thick, and the finest six thousand four hundred apertures in a square inch, and the wire one two hundred and fiftieth of an inch thick. When such a lamp is introduced into an explosive mixture of carburetted hydrogen and air, the cylinder becomes filled with a bright flame, and this flame continues to burn as long as the mixture is explosive. When the quantity of air is to that of carburetted hydrogen as twelve to one, the flame of the wick appears within that of the fire-damp; but when the ratio is as seven to one, the flame of the wick disappears. When the thickest gauze is used, it becomes red hot, and yet no explosion takes place.

In some subsequent researches on the combustion of gaseous mixtures, Sir H. Davy proposes to supply the coal miners with light in mixtures of fire-damp containing too little air to be explosive, by means of a small cage made of platinum wire one-seventieth or one-eightieth of an inch thick. If the flame should be extinguished by the quantity of fire-damp, the glow of the metal will be sufficient to guide him; and by placing the lamp in different parts of the

Machinery

Dr. Clanny's safety lamp.

Safety lamp b:
Sir H. Davy.
Fig. 6

Manufactures. gallery, the relative brightness of the wire will show the state of the atmosphere in these parts.

This beautiful experiment gave rise to Mr. Ellis's *lamp without flame*, in which a coil of platinum wire, the hundredth part of an inch thick, heated red hot, and held above a glass containing ether, or alcohol, will retain its red heat, and even reach nearly a white heat, by the invisible combustion of the alcoholic or ethereal vapour. A thin sheet of platinum or palladium produces the same effect.

A more particular account of the safety lamp will be found in the volumes of the *Philosophical Transactions* for 1816, 1817, and in Sir H. Davy's *Treatise On the Safety Lamp for Coal Miners, with some Researches on Flame*, London, 1818.

Application of the Steam Engine to Navigation.

(243.) The discovery of this application is one of those extraordinary events which occur but very rarely in the History of Science, and which, when they do occur, are calculated to alter all the existing relations of Nation with Nation, and to produce their effect in every civilized part of the Earth. The aid afforded to navigation by the introduction of this power has already produced the most important results; voyages are now made by sea with a speed, facility, and constancy, which is scarcely exceeded by our most regular land communications. Steam vessels are daily leaving our outports, which convey the mails, packages, and passengers to various ports on the opposite side of the Channel; to others, in the Baltic, to Portugal, Spain, Gibraltar, and to the Islands in the Mediterranean, whereby a correspondence is kept up between these distant parts, with a regularity highly gratifying in private life, and of the greatest importance in all commercial and political transactions. One or more passages have been effected between the Continent of America and England; another from England to India; and there is great reason to hope that a few years will render such voyages no uncommon occurrences. At present, these vessels have been but little employed for the purposes of war, but there can be no doubt, whenever this Country shall be again called upon to show her power, that steam vessels will be found of the utmost importance: they may never perhaps become fighting ships, but in towing others out of ports and harbours, or into action, in conveying troops, in removing or transporting military stores, and in bearing despatches and intelligence, they cannot fail of acting a most important part; and the numbers we are annually adding to those already in the Royal Navy, is a sufficient indication, that their value is duly appreciated by the members of the British Government. These considerations will lead us to enter at some length into a description of this important application of steam power.

History of steam navigation.

First projected by Hulls.

(244.) *Historical sketch of the progress of steam navigation.*—It appears that Captain Savery himself entertained some idea of employing the steam engine on shipboard, by propelling a paddle wheel with water raised by pumping; but in the form in which his engine existed in 1702, this can scarcely be considered in any other light than the exuberance of fancy. There is, indeed, no question that the first plausible idea of this kind is due to Jonathan Hulls, who, on the 21st of December, 1736, obtained a patent for what may be strictly considered a steam vessel. The letters patent, and a description of this boat, illustrated by a plate, was

published in a Tract by Hulls, in 1737, under the following title, *A Description and Draught of a new invented Machine for carrying Vessels or Ships out or in of any Harbour, Port, or River, against Wind or Tide, or in a Calm*. As the origin of the invention of steam boats has been strongly contested, this pamphlet, which it is now very difficult to obtain, has been brought forward to prove that Jonathan Hulls was the first person who suggested the power of steam as a means of propelling paddle wheels.

Machinery.

In describing his mode of producing a force sufficient for towing vessels and other purposes, the patentee says, "In some convenient part of the tow boat, there is placed a vessel about two-thirds full of water, with the top close shut; this vessel being kept boiling raises the water into steam, which being conveyed through a large pipe into a cylindrical vessel, and there condensed, makes a vacuum, which causes the weight of the atmosphere to press on the vessel, and so presses down a piston that is fitted into this cylindrical vessel, in the same manner as in Mr. Newcomen's engine, with which he raises water by fire.

"It has been demonstrated, that when the air is driven out of a vessel of thirty inches diameter, the atmosphere will press on it to the weight of four tons sixteen hundred weight and upwards: when proper instruments for this work are applied to it, it must drive a vessel with great force."

It would be, perhaps, useless and uninteresting to describe the method which Hulls proposed for obtaining the rotation of the paddle; it will be sufficient to say that it was extremely ingenious, and was preferred by him to the crank, which is alluded to by him as applicable to the purpose.

In speaking of this first actual proposition for propelling vessels by steam, we cannot help noticing a very illiberal remark by Dr. Renwick, an American author, on the subject of steam navigation, or rather, on the steam engine in general. Dr. Renwick's *Treatise* upon the whole is very ingenious and sensible; but the author, we must think, is unjust in his remarks with reference to Hulls, whose attempt, he says, "so far from classing amongst ingenious and profitable improvements, we should rather be inclined to rank amongst those which, from their obvious impracticability, merit the oblivion into which they instantly fall." This is sufficiently illiberal, standing by itself, but to illiberality the author adds also inconsistency, when immediately before he states, in mentioning some claims of an officer named Blasco de Garay, who, according to certain records, "made at Barcelona, in the year 1543, was the author of an experiment on a vessel, which he forced through the water by an apparatus, of which a large kettle filled with boiling water was a conspicuous part." "If this be true," Dr. Renwick remarks, "and we have no reason to doubt the authenticity of the record, De Garay was not only the inventor of the steam boat, but the first who was successful in applying steam to useful purposes. He was, however, too far in advance of the spirit of his Age to be able to introduce his invention into practice." A compliment, we cannot help thinking, which is quite as much due to Jonathan Hulls as to Blasco de Garay.

In 1775 a Mr. Perier constructed a small boat, which was tried on the Seine. Its motion was slow, the engine having only the power of one horse; but it may be said to have been a successful experiment, although the practice was not continued by its inventor.

Experiments by Perier.

Manufac-
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By Jouv-
fray.

In 1781, the Marquis de Jouffray built a steam boat at Lyons, of a large size, that is, 147 feet long. The current of the Saone being very gentle, was well adapted for such experiments, and became the place of trial; but as in most other first attempts, different accidents occurred, and at length the Revolution put a final stop to them, the inventor, like most others of the privileged Orders, being forced by circumstances at that time to leave France, and to seek shelter in a foreign land.

By Ram-
say, Fitch,
Symington,
and others.

About this period also, experiments on this subject were going on in America, conducted by James Ramsay of Virginia, and by John Fitch of Philadelphia; as also in Italy by M. Serratti; and in Scotland by Mr. Miller of Dalswinton, who, having seen a model of a steam carriage, invented by Mr. William Symington of Falkirk, was so much pleased with it, that he directed the inventor to make a small steam engine to work a twin or double boat. This engine having been accordingly executed and put on board a vessel, an experiment was made with it in the year 1788, which answered so well that he had another boat made on a larger scale; which he tried on the Forth and Clyde canal in 1789, which was ultimately given up in consequence of the injury done to the banks of the canal by the violent agitation of the water by the motion of the paddle wheels. The method employed by Mr. Symington for making the connection between the paddle or rowing wheel and piston, was by placing the cylinder in a horizontal position, which it was supposed would be attended with the advantage of avoiding the necessity of a working beam. The piston was supported in its position by friction wheels, and communicated its motions by means of a crank to the paddle wheels, which were placed in the middle of the boat towards the stern; and on this account it became necessary to have a double rudder connected by rods, which were moved by a winch placed at the head of the boat. The steam engine differed but little in its action from that improved by Mr. Watt. Means were also provided to reverse the motion of the wheels, and put the boat back if necessary.

A variety of other methods of applying the force of steam to the propelling of boats were now attempted. In 1795, a very ingenious apparatus was invented by Lord Stanhope, and tried by that Nobleman in Greenland Dock. In this experiment the paddles were made to resemble the feet of a duck. This plan was also attempted in America, but does not seem in either case to have answered the expectations of the projectors. A boat was tried on the Bridgewater canal, which had two wheels on each side, and an endless chain with a number of paddles attached to it passing over them. This, however, was not attended with complete success.

In 1800, Mr. Linnaker obtained a patent for propelling vessels by forcing a stream of water from the stern, while an additional supply was at the same time drawn in from the head of the vessel. This contrivance seems to have been introduced nearly a century back; and has been repeated within a few years, but the principle is altogether fallacious.

The Marquis de Jouffray returned to France in 1796, and then found that M. de Blanc had secured a patent for building a steam boat, and the former applied to Government to have the experiments stopped, being an infringement of his prior right; but the Government were at that time too busy to attend to his appeal, and M. de Blanc proceeded, but with what success does not appear.

(245.) At this time, also, Mr. Fulton was carrying on his experiments on the Isle de Cygnes, and M. de Blanc in his turn complained of the invasion of his rights. Mr. Fulton, however, stated, that it was not his intention to remain in France, and he did accordingly soon afterwards return to America. Fulton, indeed, returned to his own Country for want of proper support in Europe. It appears from a Report of the Institute of France, that he made an offer to Bonaparte, then First Consul, to employ steam boats in the flotilla which was then preparing for the invasion of England; but it was rejected. Despairing of success in the Old World, Fulton directed his attention to the New, and resolved to convey the invention which he had just perfected in the bosom of France across the Atlantic. He was encouraged in the design by Mr. Livingston, then Ambassador from the United States to the French Government. Mr. Livingston himself was the author of several plans for navigating vessels in the open sea by the agency of steam, having proposed successively to employ horizontal wheels, wheels with oblique surfaces like those of a mill, paddles like ducks' feet, scoops, endless chains, &c. The importance of steam navigation was so much felt, and the possibility of supplying the force of the wind by mechanical power so generally acknowledged in America, that in 1798 the State of New York granted Mr. Livingston a patent for twenty years, on the express condition that before the 27th of March, 1799, he would produce a boat that would go at the rate of four miles an hour. He made use of a steam engine five or six times larger than that used by Mr. Perier, and was more successful, but did not obtain the velocity required by the Legislature, because the power he applied was still too small. Fulton made use of more than treble this force, his engine having been of twenty horse power, made by Boulton and Watt, and sent out by them to America. This was soon afterwards put on board a boat built for the purpose, which commenced running in 1807, between New York and Albany, a distance of a hundred and twenty miles, which was performed in from thirty to thirty-two hours.

The account which Fulton himself has given of the first voyage, or rather of the first starting, is very expressive of the discouragement which every experimenter has found to follow some trifling interruption or impediment. In his case an accident occurred soon after the vessel was under way: the parties witnessing the attempt, although not unfriendly, expressed their fears of success; they had most of them "foreseen something of the kind," "it was a pity so much expense had been incurred," and other remarks of a similarly disheartening tendency. The repairs, however, were made, the boat again proceeded, and the doubts and fears of the party were changed into joy and congratulations. The extraordinary exhibition of this vessel, and the effect it produced in the minds of common observers, is thus described by some American Journalist.

"She had the most terrific appearance from other vessels which were navigating the river. The first steamers, as others (in America) yet do, used dry pine wood for fuel, which sent forth a column of ignited vapour many feet above the flue, and whenever the fire is stirred a galaxy of sparks fly off, and in the night have a very brilliant and beautiful appearance. Notwithstanding the wind and tide were adverse to its approach, they saw with astonishment that it was rapidly coming towards them; and when it came so near that

Machinery.

Fulton
made the
first suc-
cessful ex-
periment.

Manufactures.

the noise of the Machinery and paddles were heard, the crews, in some instances, shrunk beneath their decks from the terrific sight, and left their vessels to go on shore, while others prostrated themselves and besought Providence to protect them from the approach of the horrible monster which was marching on the tides, and lighting its path by the fires which it vomited."

It would be unjust to refuse to Fulton the glory of this successful experiment: at the same time he had competitors not far behind him in point of time, and not at all in respect to success. Only a few days' delay in the experiment of Fulton would have conferred all the honour on his Countryman Stevens. That gentleman commenced his experiments on steam navigation in 1791, and injured his private fortune considerably in his various trials. It was not, however, till 1807 that he and his son succeeded in obtaining a useful result. The exclusive privilege of working a boat in the State of New York by steam power, was granted to him who should first propel a vessel in this way at four miles per hour; and Stevens's boat effected this only a few days after Fulton's experiment, and totally independently of him. Being, however, by the conditions shut out from the privilege of working his boat in the State of New York, he adopted the bold measure of conveying his vessel to the Delaware by sea; and thus the boat so near reaping the honour of the first prize, was, in fact, the first to navigate the ocean by the power of steam.

These voyages may be said to have been final respecting the applicability of steam to the propelling of vessels, at least on rivers; and Companies were quickly formed in America for establishing such boats on their various waters. The powers of the engines and the sizes of the boats were increased, and with them the general speed of the vessels. Success in these trials excited further undertakings; a great number of boats were already in steady employ by our Transatlantic brethren, before any good practicable steamer appeared in Great Britain; and the immense progress they have since made, may be judged from the following lists, copied from the *American Almanac* of 1832.

Number of American steam vessels on the Western waters.

(246.) *Whole Number of Steam Boats built on the Western Waters. (Ohio.)*

Year built.	Whole Number.	Now Running.	Lost or worn out.	Of the boats now running there were built at
1811	1	..	1	Cincinnati..... 68
1814	4	..	4	Pittsburgh..... 68
1815	3	..	3	Louisville 2
1816	2	..	2	New Albany..... 12
1817	9	..	9	Marietta 7
1818	23	..	23	Zanesville 2
1819	27	..	27	Fredericksburgh... 1
1820	7	1	6	Westport..... 1
1821	6	1	6	Silver Creek..... 1
1822	7	..	7	Brush Creek..... 1
1823	13	1	12	Wheeling 2
1824	13	1	12	Nashville 1
1825	31	19	12	Frankford 2
1826	52	36	16	Smithland..... 1
1827	25	19	6	Economy..... 1
1828	31	28	3	Brownsville..... 6
1829	53	53	..	Portsmouth..... 3
1830	30	30	..	Stenbenville 2
1831	9	9	..	Beaver..... 2
				St. Louis..... 1
				New York..... 1
				Philadelphia..... 1
				Not known where.. 10
	348	198	150	198

Of this whole number, one hundred and eleven built at Cincinnati, sixty-eight were running in 1831.

Of the 150 lost or worn out there were	Worn out.....	63
	Lost by snags.....	36
	Burnt.....	14
	Lost by collision.....	3
	Lost by other accidents not ascertained	34
		150

Steam Boats on the Mississippi.

(247.) St. Louis is 1200 miles by the course of the river above New Orleans, and is, next to that city, the largest and most commercial town on the Mississippi. In the Summer of 1831, there were six steam boats regularly employed between St. Louis and New Orleans. A trip from one place to the other and back again usually occupies twenty-four days; the shortest time in which one was ever made is eighteen days. The usual fare for cabin passengers descending twenty dollars; ascending twenty-five dollars; for deck passengers five dollars either way. Freight per 100 pounds descending twenty-seven and half cents; ascending sixty-two and a half cents.

From St. Louis to Louisville 630 miles; six boats regularly running in 1831; usual time of a trip ten or eleven days; the passage one way usually being somewhat more than three days. Fare of cabin passengers about fifteen dollars each way; deck passengers four dollars; freight about twenty-five cents per 100 pounds. One boat also runs regularly to Cincinnati, 150 miles above Louisville.

From St. Louis to Free River about 480 miles; three steam boats regularly employed in 1831; time occupied by a trip about ten days; fare for passengers ascending fifteen dollars; descending nine dollars. The route of one of the boats occasionally extended to St. Peter river, 400 miles further up.

In 1831, two boats were employed in running from St. Louis up the Missouri to Franklin, 200 miles; and to Port Levenworth 200 miles further. Freight to Franklin seventy-five cents per 100 pounds; and to Port Levenworth from 1.25 dollar to 1.50 dollar; from Franklin down twenty-five cents per 100 pounds.

From St. Louis to Pekin, on Illinois river, 180 miles, two or three boats regularly employed in 1831. Steam boats come occasionally to St. Louis from Pittsburgh.

Steam Boats and Team Boats in Lower Canada.

(248.) Plying on the St. Lawrence sixteen steam boats, four team boats. Navigating between Quebec and Montreal sixty river crafts of twenty-five to a hundred tons burden; rate of freight per ton 7s. 6d.

Square-rigged vessels on the stocks at Montreal, two; Ditto Quebec, nine; small crafts, two.

There are also two steam boats on the Ottawa river, plying between Grenville and Hull; one been La Chene and Point Fortune, and one between La Chene and the Canadas.

Steam Navigation in Great Britain.

(249.) It was not till 1812, that the first successful experiment was made in Scotland. This was a boat established on the Clyde, for the conveyance of passengers; First experiments in Scotland.

Manufac-
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but even here the engine was only a three horse power. The vessel had also a great draught of water, a construction which subsequent trials have proved to be very disadvantageous. The success of this experiment, however, such as it was, led to many other trials, and it was soon seen that considerable power was necessary. Great power, however, could only be obtained by engines of a large size, which occupied considerable space in the vessel, an inconvenience, which, it was feared, at one time would be a great drawback on the general utility of the invention.

In order to reduce the space of the engine within the smallest possible compass, recourse was had to high pressure engines, and the steam was heated up to a high temperature to increase its elastic power; this led to various accidents from the bursting of the boiler. Copper, wrought iron, and cast iron were successively made use of; still, however, many accidents occurred, both in America and in England, till at length one attended with very fatal results happened on the Norwich river; in consequence of which a Committee was appointed by the House of Commons in 1817, "to consider of the means of preventing the mischief of explosion from happening on board steam boats," &c. The prudence and wisdom of this measure has since been made manifest, by the unfrequency of such accidents in English steamers, while the American Journals are perpetually making statements of the frightful sacrifice of life occasioned by a want of proper care and proper legislative enactments on this subject. At the moment we are writing we find the following list of accidents given by an American Paper, and the subsequent observations of the editor. The paragraph is as follows.

"In looking over our file of Papers for the last six weeks, we find that we have recorded no less than twelve steam boat disasters, attended with a loss in the aggregate of more than 100 lives. They are as follows: New England, boiler burst, 16 lives lost; St. Martin, burnt, 30 or 40 lives lost; Capstan, burnt, 20 or 30; Illinois, boiler burst, 13 or 20; Thomas Yeatman, boiler burst, 7; Columbia, sunk, 4; Paul Pry, boiler burst, 1; a total of 91 to 118 lives lost. George Washington, wrecked; Rapid, sunk; Black Hawk, burnt; Peruvian, sunk; Chippewa, sunk. Why is it that English steam boats are so safe to travellers, and American steam boats so unsafe? Why is it that more lives are lost on board American steam boats in one year, than on board English steam boats in ten years? Cannot the difference be partly accounted for by the fact, that in England very strict regulations are prescribed and enforced by the Government in relation to steam boats, and in the United States none? If not, can any man tell how the fact is to be accounted for?" *American Paper.*

A few days after the *American Advertiser* says:—It has been estimated that 1500 persons have lost their lives in this Country, during the past three years, by the bursting of steam boilers. Since July, 1832, (the present date June 17, 1834,) sixty-seven steam boats have been lost or abandoned on the Western waters.

How far the legislative enactments of the British Parliament may have been instrumental in producing the degree of safety which is experienced in English steamers, it is not, perhaps, easy to determine; but certainly the inquiry itself, in which the opinion of the most celebrated engineers was taken, and their attention thus necessarily directed to the subject, elicited many useful observations, and valuable practical hints, which have since

been adopted; and to these, perhaps, rather than to the enactments which followed, we are indebted for the safety in our vessels referred to by the *American Journalist*.

Seeing then the importance of this inquiry, and referring the reader to Art. 183, where the accidents to which steam boilers are liable is fully illustrated, a part of the evidence, and the various propositions and opinions given in it relative to this subject cannot be uninteresting to the reader; we therefore make no apology for giving this Abstract and Report, at some length, in the following pages.

(250.) *Mr. Bryan Donkin* was the first witness examined. He stated that he had been down to Norwich to inquire into the cause of the explosion of the steam boat at that place, and was accompanied by Messrs. Bramah and Collinge: that he was of opinion that the immediate cause of the explosion had been the use of steam of very high expansive power, and that the proximate cause was a deficiency in the strength of the end of the boiler. The boiler was cylindrical; the cylindrical part and one end were of wrought iron, the other end was of cast iron. It appeared to him to have been previously wrought iron, but that the wrought iron end had been cut off, and a cast iron end substituted in its place, and that any boiler so constructed was unsafe. He considered that the difficulty of obtaining a proper degree of strength at all times in the materials of which boilers may be made arose from the constant deterioration which such boilers must be exposed to by the action of the fire, and from the various degrees of expansion operating on different parts of the boiler, and thought there was an advantage to be derived from the use of high pressure engines, on board boats which are necessarily loaded differently at different times. This different loading requires a different power in the steam engines, and the high pressure engine is capable of having this additional power given to it, without any difficulty; whereas in the low pressure engines they are confined to the force assigned them.

Mr. Donkin being questioned respecting the saving of fuel in Woolf's engine, replied, that there is considerable saving in Woolf's engine, but in the common high pressure there is but little. He considered the length of time a boiler properly constructed, and constantly used, could be worked with safety to be extremely uncertain: had known one boiler worn out in six months, and another used for seven or fourteen years. The strength of cast iron boilers is extremely uncertain: cast iron contracts in various degrees in different parts, and therefore is liable to break: had no doubt that cast iron boilers were dangerous when used for steam of high expansive force. He thought it more practicable to make a boiler of the malleable metals to resist a high pressure, as far as the tenacity of the metals is concerned; but another difficulty occurs, which prevents the application of the malleable metals to boilers for high pressure engines, which is, that of rendering the joinings of plates secure. The witness considered that wrought iron boilers are more common than cast iron, but that cast iron would be cheaper if made of equal strength, but more liable to explosion from the frangible nature of the metal. In case of the explosion of a cast iron boiler, the metal is broken into fragments, and driven off with great violence in various directions, whereas a wrought iron boiler would give way without such effect. Generally a rent takes place, but he had seen one instance of a wrought iron boiler, where the whole of the upper part was rent from the bottom, driven through the house in

Machinery.

Parliamentary inquiry on the safety of steam vessels.

Manufac-
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which it was placed, and carried to a considerable distance, but had never heard of an explosion of any consequence of a low pressure boiler, merely the giving way of the plates from wear, but not such a bursting as could be called an explosion. The feeding of low pressure boilers by a column of water, is a great means of their safety, but they ought to have a safety valve besides. Low pressure boilers, employed in boats, are not fed by a column of water; it would be inconvenient, in consequence of the motion of the vessel. Had seen very few boilers constructed for the purpose of a low pressure engine, that would sustain a pressure of ten pounds per inch, without occasioning considerable leakage, or without forcing the joints; the explosion of them, that is of low pressure boilers, is not likely to do much mischief, even when made of cast iron. The expansive force of steam, employed in high pressure engines, is very variable, from thirty pounds to one hundred and twenty upon the square inch, or even perhaps higher than that.

Instances have been known in which a boiler has been worked at one hundred and sixty and one hundred and eighty pounds per square inch. The most eligible proof boilers can be exposed to, is by water, and a pressure should be employed double that to which they are intended afterwards to be subjected. Had no doubt that Cornwall had derived an incalculable advantage from the use of high pressure engines.

(251.) *Seth Hunt, Esq.*, formerly commandant of Upper Louisiana, on his examination, stated, that in the United States a great number of steam boats had been established. The first was at New York; there were then running between New York and Albany ten boats; two between New York and the State of Connecticut; four or five to New Jersey; besides the ferry boats that pass and repass across the river, of which there were three or four; those boats work all by low pressure engines; no accident has ever happened to any one of them; they have been running since the year 1807; and the boats at Albany perform about forty trips each per annum. They go up the distance of a hundred and sixty miles in twenty-one hours, and come down in nineteen; sometimes a little longer, but never shorter than nineteen. Some of them went about seven miles an hour in still water; some boats have gone nine, ten, or eleven knots, but that is under particular circumstances. They have come from Newhaven to New York, ninety miles, in six hours and a half, without any sail. They have a sail and a mast, which they can lower down and raise up to take advantage of a favourable wind to assist them in their passage. Those which go to Albany pass up the North River, and the others to Connecticut pass through what is called Long Island Sound, which is forty miles broad in one part of it. On the River Delaware there are a number of boats also established, which ply between Philadelphia and Trenton, in New Jersey; and Philadelphia and Bordenton, in New Jersey; also others between Philadelphia and Newcastle, and Philadelphia and Wilmington; besides ferry boats which pass and repass the Delaware. Several of those boats have low pressure engines, others have high pressure engines, from one hundred to one hundred and forty pounds the square inch, and as high as one hundred and sixty; but those engines are constructed upon Oliver Evans's plan, called the Columbia plan. There are no cast iron boilers in America: the witness presumed that might arise from their not having founderies in which they can cast them sufficiently large;

VOL. VII.

they are all wrought iron boilers or copper; all those Machinery, which have to pass through salt water are copper. The boat Etna, which passes between Philadelphia and Wilmington, is a high pressure engine, and outstrips all the other boats. There is no competition at all between them. There are boats from Baltimore to French Town and back, regular boats, two lines of boats; one leaves Baltimore one day, and the other the next; they pass every other day alternately. There are other boats from Baltimore, which go to Norfolk; there they pass a still wider part of the Chesapeake, which may be sixty miles wide. They have been to New London, which is still more exposed; and have been up to New Hertford. Those were low pressure engines. On the Potowmac there are also steam boats, and on the James River, which pass between Richmond and Norfolk. The largest boats in America were those on the Mississippi, the Etna and the Vesuvius, which ply between New Orleans and Natchez; they are four hundred and fifty tons, and carry two hundred and eighty tons merchandise, and one hundred passengers; seven hundred bales of cotton besides the passengers are transported to New Orleans. Mr. Hunt recollected only three accidents to have happened to steam boats in America. (These have, however, increased to a frightful amount since that period, as is seen by the memorandum before referred to.)

(252.) *Mr. Timothy Bramah* was then called in and examined. Understood that the boiler at Norwich was worked generally with a pressure of sixty pounds on the inch, but might probably be worked at one hundred and twenty at the time of the accident. Should think it not equal to the working of sixty, having been only three-fourths of an inch, and a sixteenth in some places, in thickness, and it was four feet in diameter at the end; it was a flat end to the cylinder like a drum. Did not think that a high pressure engine, under any guard that can be applied to it, is a safe engine to use in a steam boat. Apprehended that a boiler upon a proper construction, of wrought metal, may be tried with a force so little exceeding that pressure which it is intended to bear, as not to incur any risk of being injured in the proof, and to have a complete surplus of strength, so as to enable it to be afterwards used without any danger. Recommended a double safety valve, to lock one up, and to have it examined once a week, or as often as might be necessary, to see that its action was perfect. Had seen many cast iron vessels burst as well as wrought iron. Observed that the wrought iron generally tears and opens out, thereby admitting the fluid to escape. It is generally the fluid which does the mischief when the wrought iron is used, and it is both the fluid and the material which do the mischief when the cast iron bursts. The effect in cast metal is, to carry the pieces of the metal to a considerable distance, which is seldom the case in the wrought metals, unless where there is any cold shut in the metal: the cast iron bursts like a shell, projecting the fragments to a considerable distance.

(253.) *Mr. John Taylor*, of Stratford in Essex, controller of a district of copper mines near Tavistock, was next examined. He was by report acquainted with the accident which had lately happened at Norwich. He stated with respect to the impropriety of cast iron compared with wrought, that he had constructed one of the first high pressure boilers precisely in the same manner with that on board the Norwich boat: the boiler was proved

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Manufac-
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to one hundred pounds per square inch, by the water proof; but it was commonly used with about forty pounds pressure; the cast iron end, however, broke one day with less than twenty pounds pressure of steam, the fracture being caused evidently by the heat expanding the cast iron end unequally, and being thereby kept from the form it would otherwise have assumed. The witness stated that he had seen the Wells Street engine which had exploded with such fatal consequences: it was of unequal thicknesses, badly cast, from small furnaces, and the contact of the iron not complete; it did not meet in fusion. It was intended to boil sugar; the thickness was intended to be, doubtless, about two inches or two inches and a quarter, but by inserting the core unequally, the thickness on one side was three-quarters of an inch, on the other side the thickness of the metal was two inches and a quarter, or thereabouts; therefore to the general objections to cast iron, was added a most improper construction. Understood from the men who were working there (the Frenchmen) that there had been something like a mercurial gauge attached to it, but that the mercury never fluctuated; it indicated nothing; that the safety valve was loaded down with weights which he could not collect, and therefore did not ascertain the pressure; it was probable there was a pressure of more than one hundred pounds per inch.

Besides the common safety valve, which may be at the discretion of the workman, he conceived it essential to have another, which should be under the control of the master or proprietor of the works. Boilers have been weakened very much by the water having been evaporated too low, so that the bottom begins to be acted upon by the fire and weakened. A hole having been previously bored in the bottom, where the fire acts, may be rivetted by a piece of lead, so that the lead remains perfectly secure as long as it is covered with water, but the moment the water leaves it the lead melts; the steam is blown out through the hole and puts out the fire; besides giving the signal of what is wanted, it at once puts an end to the cause of danger. Mr. Taylor considered that the mercurial gauge not only acted as a safety valve, but it has the advantage of exhibiting, during all times of the boiler's working, the state of the steam within the boiler, by the fluctuation that takes place in that column, as indicated by the index upon the surface of the mercury, and the state of that mercurial gauge is observable every moment. If the mercury becomes stationary, one would strongly suspect that the tube was stopped, therefore it would point out itself instantly that it had become not what it ought to be; the safety valve has not that advantage, as it does not indicate any thing till the steam is blown out by raising the weight.

He had not seen the explosion at Wells Street, but was upon the ruins immediately after. The effect seemed to be tremendous; it knocked down the whole building, which was a sugar-house of five or six stories high, and fragments appeared to have been thrown in every direction; and the boiler itself was shattered into a great number of pieces. He considered that if it had been a wrought iron boiler and had burst, it would not have produced the same effect. He thought that copper is the best metal for boilers, but that with good wrought iron, they may be made perfectly safe up to the estimated strength of from four to five hundred pounds pressure per inch. From his experience he saw no advantage in exceeding a pressure of forty or fifty pounds per

inch; and was of opinion that, in order to save coal. Machinery. in steam vessels, high pressure steam becomes an object of great importance if applied upon the principle that Mr. Woolf in the first place introduced; but which has been applied by Mr. Sims and some others; and was of opinion that high pressure boilers might be made with equal safety as low pressure boilers. In France, at Crusae, some very good engines were erected by Mr. Wilkinson at a large work: they were on Boulton and Watt's principle; one of them blew up and killed several persons. Had heard of other instances of low pressure boilers blown up, but these were not within his own knowledge. Conceived that the mercurial gauge, if of sufficient bore, might be applied with ease to the high pressure boilers, so as to produce safety as certainly as the column of water, which is in fact a water gauge, as usually applied to the low pressure; and there is no difficulty whatever in constructing a safety valve, so as to operate with certainty, and to be safe from any impediment which the engineer might intentionally place in the way of its operation without any considerable expense.

(254.) Mr. Collinge, in his examination, stated that he considered the cause of the explosion at Norwich to be the bad construction of the boiler, which was composed entirely of wrought iron except one end which was cast iron. He stated in respect to the material of which boilers in general should be made, that any material under very severe pressure is liable to fail, and cast iron in particular, because in large bodies it is known that the air cannot wholly escape in a state of fusion. He had occasionally had large masses of cylinders and pans to break up, and had frequently found cells where the air could not escape, so that there is no certainty as to the solidity of cast iron: there is certainly a much greater dependence upon wrought iron or upon wrought metal; perhaps it would be better to include copper. More mischief arises from the bursting of cast iron boilers, because cast iron flies off in fragments, and wrought iron, from its tenacity, only rends. He was acquainted with an accident that occurred at Malden, where a boiler, nineteen feet long, was blown off from the seat of its connection with the base. He found in making wrought iron boilers, that if he made them of metal of a considerable substance, they could not be so well united to make them steam tight; the rivets are put in hot, and when they are hammered to secure the joints they get cold, shrink, and do not fill the hole through which they have passed. He thought that safety valves do not always open at the proper pressure from causes that we cannot ascertain; that a column of mercury would be a judicious application, but it requires such an altitude as not to be very easily applicable to boats in consequence of the agitation of the vessel. He had made several boilers; found that if the plates were thick beyond the dimension usually employed for condensing engines, the seams do not prove equally steam tight. He considered that if a high pressure engine could be made with equal security, it would be more convenient on board a boat than a condensing engine, as it would take less room. Believed that the principal source of the explosion of high pressure engine boilers of cast iron, arises from allowing them to get cool too suddenly, and raising the steam too rapidly, whereby the metal contracts and expands at a period when we cannot investigate its occurrence: wrought iron is not subject to that danger. He found difficulty in making boilers steam tight, even

Manufac-
tures.

for condensing engines, where the plates were of a thickness fit to undergo high pressure; and considered, in consequence, that it was impossible to construct a boiler that would render a high pressure engine on board a steam boat perfectly safe.

(255.) *Mr. William Chapman* was of opinion, all engines, whether high pressure or low pressure, are dangerous to the passengers, unless due precaution be taken to emit the steam when exceeding a given pressure; for in low pressure engines the boilers are always liable to burst or to alter their form, when the pressure becomes superior to the resistance. All boilers but those that are cylindrical in the section, and with hemispherical ends or portions of spheres or cones or conoids, are liable to alter the form by the natural expansive force of the steam; and therefore all boilers but of those forms owe their safety to their weakness, because if weak they will alter their form without danger, and if strong, they have been known to bend the iron so abruptly as to break asunder.

He also considered that high pressure engines could only be rendered safe on board a vessel by having the boiler cylindrical, with curved ends, and the cylindric part of a limited diameter, with a competent thickness of wrought metal, either iron or copper, and the plates secured to each other by a double line of rivets. It is also requisite that there should be two safety valves, each laden with any determinate weight per superficial inch, on the narrowest part of the seat of the valve: one of those valves should be at perfect liberty to be raised at the pleasure of the manager, because sometimes it is expedient to raise it; the other should be under a cover of such a description as not to be opened at all, at the discretion of the engineer, but with sufficient apertures for the emission of the steam, and for any of the passengers to see that the valve was not made fast. It is also requisite that there should be a mercurial gauge of not less than an inch in diameter, and whose longest limb should not be greater than $2\frac{1}{2}$ for every pound per inch upon the safety valve. It is necessary, by occasional inspection, to take care that the mercury does not stiffen by oxydation, occasioned by the heat and motion to which it is in a slight degree liable: a high pressure engine thus guarded might be used in a steam boat with safety to the passengers, so long as the boiler was kept in order.

(256.) *Mr. Philip Taylor* considered the first and most material point to be attended to in the construction of high pressure boilers is, that the diameter should be small in proportion to their capacity; and that as small a proportion of the external surface of the boiler as possible should be exposed to the destructive action of the fire; and that the portion of the boiler so exposed, should be so situated and guarded, that in case of explosion the least possible mischief would arise. In the boilers which he had made use of, no portion of the boiler is exposed to the action of the fire without its being constantly covered with water; and the fire is applied under an arch of not more than two feet and a half in diameter: this provides against any extensive rent taking place in the event of explosion. The boilers he had generally employed, are constructed of malleable iron, commonly known by the name of charcoal iron, rivetted together and secured by strong wrought iron bolts. From observing the danger arising from the introduction of flat cast iron ends, he had terminated the ends of his boilers by wrought iron ones, nearly hemi-

spherical: this mode of construction, as far as his experience had gone, combines more strength and durability than any other. The precautions he had made use of to guard against the misuse of such boilers, have been by adapting to them two safety valves; one under the control of the engine man, the other secured in a strong cast iron case, locked down and loaded with such a weight as would suffer the steam to escape when it had arrived at an improper degree of expansive force. In order to add to the security given by safety valves, he in every instance attached to the boiler a mercurial column, the bore of which is proportioned to the size of the boiler; and he had considered an iron tube of an inch diameter sufficient to guard against accident, when applied to a boiler four feet in diameter and twenty feet in length, because the limit given by such a column has always been far within the limit of absolute safety. The length of the external limb of the mercurial gauge has in all cases been proportioned to the strength of the boiler and the force to be applied, taking care that the expansive force of the steam would displace the mercury long before any dangerous expansive force would arise. In order to guard against the boilers being injured by the action of the fire, from a deficient quantity of water in the boiler, he inserted a leaden rivet in such a situation that it would melt as soon as it was uncovered by the water, and produce an opening which would suffer the escape of the steam. Although he made use of boilers of this construction, he considered cast iron boilers safe, provided their various parts are made of small diameters in proportion to their capacity; such, for instance, as those constructed by Mr. Woolf.

The witness thought a high pressure engine with a boiler thus constructed would be equally safe with those called condensing engines.

(257.) *Mr. Henry Maudslay*, engineer, of Lambeth, was of opinion, that high pressure engines were not applicable to boats, because the purpose of such engines was to save water, which cannot be wanted on board a vessel; the difference between the one and the other makes no ultimate saving either in weight or expense, particularly when steam boats are properly contrived. He considered it necessary to have two safety valves, and sometimes three were used. To make it quite easy for the man to move the valve, he had a sort of bell-pull going down to the place where he stokes, to pull it up every hour if he pleased, to keep it in action; because it is clear the spindle may corrode and stick fast for want of use. Supposing it not touched once a week, it is not a safety valve any longer, because a very little friction will add a great many pounds weight to the opposition the steam ought to meet with. The witness never knew a low pressure engine unsafe, but it appeared high pressure engines had been so. He likewise stated, that if steam be raised beyond five or six pounds per inch in a condensing engine, the power of the engine will not thereby be at all increased; that wrought iron is extremely safe compared to cast iron for steam boat boilers. He should not consider himself in any danger in a boat fitted with a high pressure steam engine that had a wrought metal boiler, either of iron or copper, constructed by a competent engineer, with safety valves in proper order and a mercurial gauge, provided an experienced person had the superintendence of it.

(258.) *Mr. Alexander Galloway*, who was the next witness called, said he should certainly recommend that for steam boats, the condensing engines should be used in

Manufac-
tures.

preference to high pressure engines, for the following reasons. In the first place, the great advantage that has been promised from a high pressure engine is, that it can be worked in a situation where water cannot be procured, and therefore, under this circumstance, it is for such a situation a valuable machine; but in situations where water can be readily procured, it is not so. And in reference to the comparative price between a high pressure engine and a low pressure engine, and in reference to the space that it occupies, and in reference to the superintendence that it requires, he was decidedly convinced no economy is produced. Speaking of it as a matter of safety, it will be necessary to say, that experience has fully proved, that the maximum of force to be obtained by a condensing engine, is when the steam is rarefied from three to six pounds on the inch, the engine is by far more efficient than when the steam is more rarefied; and it will appear equally clear, that whether it be a cast iron boiler or a wrought iron boiler, or a copper boiler, the force of the engine is better performed by steam at three pounds and a half, than it is at any increased expansive force: the boiler being subject only to three instead of six pounds, it must be less liable to explode or burst at that than at an increased expansive force. He should further observe, that every man who is called to work a condensing steam engine, knows, that when his steam is at three pounds and a half, it performs a greater quantity of labour than at any other time; for if it is increased it throws a vast labour on the air pump and the condenser, and retards the engine; therefore, a man has no inducement to increase the expansive force of the steam, knowing that no useful end can be obtained by so doing. All boilers on board steam boats should have the fire in the interior of the boiler, because it is of very little importance as regards safety, whether the passengers are to be endangered by an explosion, or whether the vessel is to be weakened in its timbers or essential securities, by the improper application of the fire to the boiler; therefore, he invariably recommends, that the fire should be contained in the interior of the boiler, and that there should be an additional safety valve, which should be solely subject to the superintendence of the proprietor, and that the manager of the Machine should have no possible access to it. He should certainly recommend a wrought metal boiler in preference to a cast iron boiler. The witness is of opinion a high pressure engine, using the expansive force to forty pounds on the inch, and not beyond, would be a safe and efficient engine, provided that due caution was given to the safety valve. The mercurial gauge he considered an efficient and convenient apparatus; but on board a boat, it would be constantly in the way, and it would require a great column of mercury to make it safe, and such a quantity as would be likely to do mischief if blown up. He stated there was very little difference between the consumption of coals by low and high pressure engines; but if the two were combined, as in Woolf's engine, there was a considerable saving.

(259.) *Mr. John Braithwaite* thought that a boiler might be able to bear three times the pressure intended to be put upon it; and if it did bear that pressure, and they applied two safety valves with mercurial steam gauge, properly weighed and adjusted, (one of those safety valves should be at the will of the person about the boiler, and the other no man should be able to get at,) it would be impossible to explode it. He saw the

boiler at Wellclose Square after the accident, and also conversed with one of the men who was saved. He informed him he had carried an additional weight to put on the safety valve just before the explosion; that the mercurial gauge was plugged up, so that it was useless; besides which, instead of the safety valve being weighted equal to forty-five pounds, they added a double weight, which increased it to ninety pounds upon an inch, and the boiler was very improperly made. There is no danger in a steam engine boiler if properly constructed.

(260.) *Mr. John Hall*, engineer, of Dartford, had made cast iron boilers, had proved them by a hydraulic press made for the purpose, and had gone as high as two hundred and fifty pounds to an inch, which he thought sufficient, and no accident had occurred. It was his intention the next time to try what they would bear, and had no doubt he should find them competent to the task of bearing from seven hundred to one thousand pounds per square inch. He believed they could be made stronger than wrought iron boilers; such boilers being rivetted together cannot be so strong as those cast in a solid mass. He considered it scarcely possible that any imperfection could remain after it had undergone the pressure above described. He conceived it quite practicable to adjust a safety valve to a boiler, which should not be accessible to the engineer directing the Machinery, but which should sufficiently protect the boiler from mischief.

(261.) *Mr. Alexander Tilloch's* opinion was, that by attending to what should be attended to in every steam engine, and employing proper engineers, a steam engine would be perfectly safe, whether with high pressure or low pressure. The boilers ought always to be furnished with safety valves; and if they suspect the possibility of having a stupid man, one of the valves should be covered and out of his reach with a box over it, but perforated so that it might be seen when the steam operates on it. A mercurial valve is also very good; that is, an inverted syphon, with a column of mercury proportioned to the purposes for which it is to be employed. Apprehended no danger would arise, in case of explosion, from the mercury; because the tube is always perpendicular, and if the mercury shoots out, it goes away and falls down like rain. Was of opinion, a boiler might be made safe either of wrought or cast iron; but for great strain would prefer cast iron, contrary to the opinion of many people, and the reason he preferred it was, the same for which it is preferred in making cannon. It is not possible to get thick plates of wrought iron perfect throughout; but cast iron boilers can be made of any strength; instead of having a boiler that will stand sixty, it may be made to stand six hundred, of either wrought or cast iron. Another reason why he would prefer cast iron was, that the sheet iron corrodes much quicker, and destroys by oxydation, so that a boiler may be safe when first set up and stand its proof, but very soon become unserviceable, or at least comparatively so. Boilers should always be cylindrical, and for an obvious reason, capacity should be got by length and number rather than by diameter. In case of an actual explosion, he thought that the greatest danger would ensue from the cast iron, but that a properly constructed boiler of cast iron would be stronger, and therefore could not explode so soon. A boiler should be proved with cold water if it is to be applied to high pressure. With respect to the effect of cavities, he conceived no danger could arise from the expansion of the air in them; because these cavities must be formed when the iron is at a white heat, and,

Machinery

Manufactures.

consequently, the air in it must be then more expanded than it can ever be again in practice.

(262.) *Mr. George Dodd*, civil engineer, Oxford Street, examined. Had used boilers in his steam boats with flat sides and ends, because that figure gives the greatest cubical content in the smallest space, and compactness of the Machinery and the boiler is a desirable object in a steam boat; moreover, such boilers, properly constructed, and of sufficient thickness in the plates of wrought iron, may be safely used on board steam boats having the low pressure engines. He recollected the boiler of the *Caledonia*, London and Margate steam packet, bursting at sea, by the forcing out of three of the rivets over the furnace mouth, which extinguished the fire, but it was not productive of any injurious consequences to any of the persons on board; and the *Cork and Cove* packet boat in Ireland, with two hundred and fifty officers and soldiers on board, burst her boiler when lying along side of the transport that was receiving the troops: the bursting made a fissure or opening of nine inches by eighteen, but the steam which escaped did no injury, either to the persons on board or to the vessel. The construction of the boiler of the *Norwich* boat was, in the opinion of this witness, injudicious. On examination, he found the barrel or cylinder of the boiler was of wrought iron, rivetted together, of which part he approved; but he found that one of the ends was a flat plate of cast iron, and as these two metals, under the same degree of heat, have different degrees of expansion, he thought it by no means a perfect and secure boiler.

(263.) *Mr. Richard Wright* was of opinion, both wrought and cast iron boilers might be used with equal safety; but that in proving them, they ought to be kept under the pressure a considerable time, a quarter, or even half an hour; for sudden pressure might cause flaws in the metal which is liable to give rise to accident afterwards; but if under pressure a considerable time the action of it would be evident.

(264.) *Mr. John Richter*, sugar refiner, Cornwall Place, had attended from time to time during the whole period of the construction of the *Well Street* boiler, for the purpose of boiling sugar by means of high pressure; it is necessary in such case to have a pressure of from six and thirty to five and forty pounds per inch. When this witness saw the boiler, the bottom only was put up; he was at that time informed the dome part of it was cast, but it was not sufficiently strong; the casting of another was then in hand, which was afterwards completed. It appears, that in consequence of complaints from Constant, the Frenchman in whose house it was, that it would not do its work, and his fears in pressing it on to do so, the maker of it became anxious to show that it would, and a day was appointed for this to be done. Constant, at three o'clock in the morning, began his work, and continued boiling till about eight, but boiling with a great deal of difficulty, because he was afraid of putting the engine to the pressure he required. He gave it up; he said he would boil no more; and the men in attendance, who belonged to the engineer, went to fetch the engineer. He and his men came down, and persuaded Constant to have the fire lit again. He consented, after a great deal of difficulty, and went to another pan in an adjoining building, and there he was at work when the accident happened. They were urging the steam, and actually had put an immense weight upon the lever of the valve, so as to render it totally useless. This was ascertained by a Frenchman, who saw it, and who stated

to the man that he was doing mischief and doing wrong. He was told to hold his tongue, and mind his own business; that he knew his business, and they knew theirs; the consequence was, that immediately afterwards it blew up. After this accident, he went every day to the ruins, for the purpose of satisfying himself of what had been the cause of the bursting; and saw the excavation until the parts of the boiler, which was of cast iron, were found; and then finding parts of this boiler in different places, the seat of the boiler being where it had been placed, but the rest scattered about in different directions. He measured the thickness of different parts of it; the bottom of it was two inches and a half thick, the upright sides of the bottom one inch and a half thick; the lower part of the dome was seven-sixteenths thick, and one of the parts at which it must have burst, and where the boiler was completely defective in the casting, was less than the eighth of an inch thick; it was not thicker than a crown piece: the wonder is that it stood so long, not that it burst. The boiler was not intended to be worked above forty-five pounds per inch, and was ordered to be made to sustain the pressure of a hundred pounds. The whole house was blown to pieces, which, the witness apprehended, arose from the fragments of the boiler striking the story post, by which, the support being taken away, the walls fell inwards.

(265.) *Mr. John Steel*, engineer, of Dartford, gave it as his opinion that the proof arising from the pressure of cold water, was sufficient to ascertain the safety of a boiler, which shall afterwards be exposed to the operation of fire or of highly heated steam, because he imagined it to be a great deal stronger when heated to the extent steam will heat it; cast or wrought iron he considered to be at its greatest strength when at three hundred degrees, which he believed steam never had arrived at.

(266.) *Mr. William Brunton*, the next witness called, thought the boilers for high pressure engines could be so constructed as to become useless before they are dangerous; upon the principle of having the exterior part of the boiler independent of the flue, so much so, that while the flue is injured by the action of the fire, the exterior part of the boiler remains, as to strength, unimpaired; and he conceived that a boiler thus formed, when the flue has been worn very thin, and when exposed to a greater pressure than it could sustain, the thin parts of the flue would act as so many safety valves. *Mr. Brunton* considered it possible to construct boilers which would bear an expansive force of six hundred pounds to an inch. He recommended two safety valves, one in an iron box under lock and key, and the other open to the engine man. He also employed a mercurial gauge, or an inverted syphon, which, in the event of the steam being stronger than the mercury can sustain, it will be driven out, and the boiler thereby relieve itself. The witness was of opinion the fragments separated from a wrought iron boiler by explosion, in the same manner as from a cast iron one, and that they would be projected with equal force under the same circumstances. He knew one instance in which a wrought iron boiler burst with a high pressure of steam; and a fragment, the largest piece, was carried to the distance of a hundred and fifty feet. The witness was, however, induced to prefer wrought iron boilers, from the examination of several cast iron ones, which he found cracked or broken in the lower part, which, in his opinion, arose from the unequal tempera-

Machinery

Manufac-
tures.

ture and expansion in the interior of the boiler; this unequal temperature is caused by a quantity of water at all times under the flue, and, consequently, of lower temperature than the water above the flue; thereby causing the upper part of the boiler to expand in a greater ratio than the under part, which in his opinion caused the fractures alluded to. Mr. Brunton recommended wrought iron boilers on board steam boats, if properly constructed; but it is necessary, he observed, to have at least two safety valves; the one to be placed under the lock and key of the proprietor of the vessel, so secure as not to be accessible to the engine man, and another which he should have under his own control, the valves should be nearly flat or quite so, which he apprehended would be less liable to be fastened by the difference of temperature to which the valve and the seat might occasionally be subjected.

(267.) *Mr. Josiah Jessop* stated, if safety were the only object, he had no doubt that a low pressure boiler must be more secure than a high pressure, for although either of them in the first instance may be made secure, yet from the natural wear and tear both are liable to accidents. If an accident happen to one of high pressure, its consequences certainly would be more dangerous than that of a low pressure engine. Boilers should be made to withstand a proof of two or three times the pressure to which they are likely to be exposed; the witness recommended, as a means of preventing a boiler being used at a greater power than it was intended for, the use of an additional safety valve, to which the person who worked the engine should not have access. Malleable metals, such as iron and copper, are certainly preferable, because these do not burst by an explosion, as brittle metal does, but tear; it would in all probability rend at the joints, and if the safety valves be properly adjusted to the strength of the boiler, and so constructed as to work with perfect ease, with one of them put out of the reach of the engine man, there would be no occasion for the additional aid of a mercurial gauge.

(268.) *Mr. Alexander Nimmo* employed a safety valve in the boiler of a vessel belonging to the Dublin steam packet Company, which consisted of a hemispherical cup, with its curved surface downwards, resting upon a collar, and to the bottom of the cup a weight was hung which had previously been adjusted; by this means the valve is always steam tight in every position, yet without danger of adhering, and must be lifted by the steam when it exceeds a given pressure; but the valve may also be lifted by a chain attached to its upper side, which is inclosed within the iron case, and may be drawn by the engine man, or any person on board, but does not allow him to keep it down or to confine it. The witness was also of opinion, that it is scarcely possible to form cast iron every where equally strong, and if a part be weaker than the rest, either on purpose or by accident, it will not have the safety that would be obtained by a wrought iron boiler; but in cast iron boilers it is common to have holes, and if these be filled with some metal of different melting temperature from cast iron, more fusible for instance than that, the juncture will part first, and it may be made to tear as a wrought iron boiler would do; and again, the wrought iron is so much more liable to oxydation than cast iron, that although found very efficient at first, its strength and tenacity may be very speedily altered; for these reasons cast iron boilers have been preferred where high pressure engines have been used; and in small tubes the tenacity of cast iron can

be made greatly to exceed that which can be given to Machinery.
wrought iron in the same form.

Several other witnesses were examined, who spoke of their practical opinions on most of the above inquiries, but they are not calculated to afford any further information respecting the application of engines to vessels; we do not, therefore, abridge them, but shall content ourselves with giving the following Report of the Committee, dated June 24th, 1817.

(269.) *Report.*—Your Committee entered on the task assigned them, with a strong feeling of the inexpediency of legislative interference with the management of private concerns or property, further than the public safety should demand, and more especially with the exertions of that mechanical skill and ingenuity, in which the artists of this Country are so pre-eminent, by which the labour of Man has been greatly abridged, the Manufactures of the Country carried to an unrivalled perfection, and its Commerce extended over the whole World.

Parliamentary Report
on the safety
of steam
boat boilers.

Among these, it is impossible for a moment to overlook the introduction of steam as a most powerful agent, of almost universal application, and of such utility, that but for its assistance, a very large portion of the workmen employed in an extensive mineral district of this Kingdom would be deprived of their subsistence.

A reference to the evidence taken before your Committee, will also show with what advantage this power has lately been applied, in Great Britain, to propel vessels both of burden and passage, how much more extensively it has been used in America, and of what further application it is certainly capable, if it may not be said to be even now anticipated in prospect.

Such considerations have rendered your Committee still more averse than when they entered on the inquiry, to propose to the House the adoption of any legislative measure, by which the science and ingenuity of our artists might even appear to be fettered or discouraged.

But they apprehend that a consideration of what is due to public safety, has on several occasions established the principle, that where that safety may be endangered by ignorance, avarice, or inattention, against which individuals are unable, either from the want of knowledge, or of the power to protect themselves, it becomes the duty of Parliament to interpose.

In illustration of this principle, many instances might be given: the enactments respecting party-walls in building, the qualification of physicians, pilots, &c., the regulations respecting stage-coaches, &c., all seem to be grounded upon it. And your Committee are of opinion, that its operation may, with at least equal propriety, be extended to the present case, on account of the disastrous consequences likely to ensue from the explosion of the boiler of a steam engine in a passage vessel, and that the causes by which such accidents have generally been produced, have neither been discoverable by the skill nor controllable by the power of the passengers, even where they have been open to observation.

Your Committee find it to be the universal opinion of all persons conversant in such subjects, that steam engines of some construction may be applied with perfect security, even to passage vessels; and they generally agree, though with some exceptions, that those called high pressure engines, may be safely used with the precaution of well-constructed boilers, and properly adapted safety valves; and further, a great majority of opinions lean to boilers of wrought iron or metal, in preference to cast iron.

Manu-
factures.

Your Committee, therefore, in consequence have come to the following Resolutions; which they propose to the consideration of the House:

1. Resolved, that it appears to this Committee, from the evidence of several experienced engineers examined before them, that the explosion in the steam packet at Norwich was caused, not only by the improper construction and materials of the boiler, but the safety valve connected with it having been overloaded, by which the expansive force of the steam was raised to a degree of pressure beyond that which the boiler was calculated to sustain.

2. Resolved, that it appears to this Committee, that in the instances of similar explosions in steam packets, manufactories, and other works where steam engines were employed, these accidents were attributable to one or other of the causes above alluded to.

3. Resolved, that it is the opinion of this Committee, that for the prevention of such accidents in future, the means are simple and easy, and not likely to be attended with any inconveniences to the proprietors of steam packets, nor with any such additional expense, as can either be injurious to the owners, or tend to prevent the increase of such establishments. The means which your Committee would recommend are comprised in the following regulations:

That all steam packets carrying passengers for hire, should be registered at the port nearest to the place from or to which they proceed:

That all boilers belonging to the engines by which such vessels shall be worked, should be composed of wrought iron or copper:

That every boiler on board such steam packet should, previous to the packet being used for the conveyance of passengers, be submitted to the inspection of a skilful engineer, or other person conversant with the subject, who should ascertain, by trial, the strength of such boiler, and should certify his opinion of its sufficient strength, and of the security with which it might be employed to the extent proposed:

That every such boiler should be provided with two sufficient safety valves, one of which should be inaccessible to the engine man, and the other accessible both to him and to the persons on board the packet:

That the inspector shall examine such safety valves, and shall certify what is the pressure at which such safety valves shall open, which pressure shall not exceed one-third of that by which the boiler has been proved, nor one-sixth of that which, by calculation, it shall be reckoned able to sustain:

That a penalty should be inflicted on any person placing additional weight on either of the safety valves.

4. Resolved, that the Chairman be directed to move the House, that leave be given to bring in a Bill for enforcing such regulations as may be necessary for the better management of steam packets, and for the security of his Majesty's subjects, who may be passengers therein.

(270.) It must be admitted, and is indeed implied, in the preceding Report, that there was a greater difference of opinion between some of the witnesses in the investigation than we might have anticipated on a scientific subject. Science, however, cannot penetrate into all the mysteries which arise in practice; and hence it follows, that the predicted results of this or that untried experiment, are liable to uncertainty. We have no doubt, however, that the practice of steam navigation has bene-

fited largely from the inquiry; and it has certainly since increased to an extent which is truly astonishing, as will be seen by the following Parliamentary Return, showing the number of boats in actual service in the several ports of the United Kingdom for each year from 1814 to 1828. The first sea voyage of an English boat was made in 1815, from Glasgow to London; and in the following year a steam vessel crossed from Brighton to Dieppe. In 1820, steam vessels were first introduced into the Post Office department, as packets between Dublin and Holyhead; and about the same time two steam vessels were built for the Naval department. Since that time the Admiralty have largely increased the number of steam vessels and their tonnage; there being several at this time equal in tonnage to frigates driven by engines of 200 and 220 horse power.

Machinery.

(271.) *Official Return of the Number of Steam Vessels, with the Amount of their Tonnage, and the Number of their Men, that belonged to the several Ports of the United Kingdom, from 1814 to 1828, both inclusive, (exclusive of Government Vessels.)*

Years.	Vessels.	Tons.	Men.
1814	11	542	65
1815	25	1,558	150
1816	34	2,064	201
1817	42	2,382	233
1818	53	3,807	305
1819	60	4,155	369
1820	78	5,086	478
1821	101	8,003	712
1822	129	11,007	924
1823	151	13,104	1,112
1824	168	14,708	1,276
1825	213	18,730	1,630
1826	285	26,904	2,278
1827	318	30,239	2,566
1828	344	30,912	2,708

The following Table shows how the above 342 vessels were distributed, in respect to the different parts of the United Kingdom, in 1828.

London	57	Whitehaven	2
Beaumaris	2	Yarmouth	4
Bristol	8	Aberdeen	4
Carlisle	1	Campbeltown	2
Chepstow	3	Dundee	4
Cowes	3	Glasgow	48
Dover	4	Port-Glasgow	5
Hull	31	Greenock	2
Ipswich	3	Inverness	1
Lancaster	1	Irvine	1
Liverpool	46	Leith	1
Newcastle	53	Kirkaldy	3
Newport	1	Grangemouth	4
Plymouth	2	Dublin	14
Portsmouth	4	Belfast	5
Southampton	4	Cork	5
Stockton	1	Drogheda	1
Sunderland	10	Waterford	1
Swansea	1		

Manufactures.

(272.) *An Account of the Number of Voyages and Tonnage of the Steam Vessels, which entered the Port of London during the Year ending the 5th January, 1826.*

Steam Vessels' Names.	Register Tonnage.	Number of Voyages.	Owners.
Superb	155	49	General Steam Navigation Company.
Talbot	77	21	
Mountaineer	188	49	
Hylton Joliffe	174	9	
Rapid	84	3	
Belfast	132	18	
City of London	146	54	
Royal Sovereign	135	41	
Brocklebank	111	30	
Earl of Liverpool	131	55	
Lord Melville	136	53	London and Edinburgh Steam Packet Company.
Eclipse	87	10	
Waterloo	134	24	
Attwood	143	18	
Soho	353	13	
James Watt	294	12	Margate Steam Packet Company.
City of Edinburgh	300	15	
Tourist	179	16	
Eclipse	155	51	Mr. Heighington.
Venus	181	38	
Albion	196	59	
Dart	162	43	Rotterdam Steam Packet Company.
Favourite	209	197	
Swiftsure	106		
Sons of Commerce	87		
London	76		
King of the Netherlands.	134	32	
Queen of the Netherlands	116	29	
Prince Frederick	154	32	
Yorkshireman	164	30	
Hero	242	22	
Victory	275	18	Yarmouth Steam Packet Company.
Albion	102	19	
Cambria	83	32	
Sir Joseph Yorke	61	57	Messrs. Joliffe and Banks.

We have not the means of knowing what the increase has been during the six years since 1828, but if we assume it equal to three times the increase of the last two years in the above list, the number of vessels at this time belonging to private individuals and private Companies in the different ports of the United Kingdom, will be 515, their tonnage 42,936, and the number of men employed in them 3998; or, in round numbers, 500 vessels, 43,000 tons, and 4000 men.

The largest steam vessel at present in Britain is the *Monarch*, belonging to the London and Leith Steam Packet Company; it was built by Messrs. Green, Wigram and Green, in 1833, from the plan of Mr. Charles Wood, of Port Glasgow. It was superintended while building by the present scientific commander, William Bain, Esq., a master in the Royal Navy, by whom we have been favoured with the following dimensions of the hull, and other particulars.

Length of keel	180 feet.
Over all	208
Beam for Tonnage	32
Hold	18.4
Extreme breadth	55.4

It is propelled by two engines of one hundred horse power each, constructed by Boulton and Watt. Cylinders 53 inches; diameter stroke 5 feet; extreme diameter of paddles 21 feet, floats 10 feet by 2½ feet; the average speed is 10½ miles. The voyage from London to Leith has been performed in 39 hours. The space occupied by the Machinery and the coal space measure 60 feet by 32 feet; the coal space will contain 140

tons. The weight of the Machinery and boilers is 226 tons. The average consumption of coals is 21 hundred-weight per hour.

This vessel makes up one hundred and fifty beds for passengers, and one hundred are comfortably and elegantly accommodated in the saloon at dinner.

The appointments of the vessel are as below:

Commander	1
Officers	3
Seamen	12
Engineers	2
Fire men and coal trimmers ..	8
Boatswain and mate	2
Carpenter	1
Cook and mate	2
Stewards	10
Female attendants	2
Total ..	43

(273.) *On the propelling and resisting forces in steam vessels.*—It is not our intention in this place to enter into inquiries relative to the stabilities of different shaped vessels, nor to investigate the resistances which vessels offer according to their form and velocity, as this belongs rather to the *Treatise on NAVAL ARCHITECTURE*. The subject which it is proposed to treat of more particularly in this place is, the force employed in propelling the vessel: the different modes which have been proposed for effecting this object; the resistance opposed to the paddles, and the resulting velocity of the vessel itself; and as in all such cases, actual practical results are more valuable than theoretical investigation, we shall, as far as possible, draw our deductions from experiments at large.

The most general, and undoubtedly the most efficient, method of propelling vessels by steam power, is by means of paddle wheels, but other principles have been had recourse to, to which it may be well slightly to allude, including also some in which manual exertion is the motive power. The first and most simple of the latter class is the employment of oars, as in rowing. This is indeed a sort of single paddle, instead of a paddle wheel, or it may be considered as a combination of a number of simple paddles, when several persons are employed in this service. This was a method much practised by the Ancients, who had attained to great skill in their modes of combining the action of the several oars, to produce the best effective result.

The action of the oar is extremely simple, and remarkably suited to the power of a man; because, by giving to it a certain length, the muscular action requisite to give it force is precisely that which a man can exert with the least possible fatigue.

If we conceive the oar thrown on land, or on the banks of a river or canal, where it can find a fixed resistance, it obviously becomes a mere lever, where the end on the land is the fulcrum, the other extremity the power, and the *rowlock* the point at which the weight, or the resistance of the water to the motion of the boat, is applied. From this effort the boat is urged forward, and it is equivalent (as far as regards the balance of the muscular power applied) to a weight being raised to that height.

If now the oar, instead of resting on the land, has its broad side exposed to the water, and the same effort be applied, the same effect will be produced, except that, in

On the propelling and resisting forces in steam vessels.

Case of the common oar examined.

Manufac-
tures.

Action of
the paddle
wheel.

Other me-
thods of
propelling.

Machinery

this case, the fulcrum yields back more or less, depending on its action against the water, and the boat advances forward so much less each stroke of the oar, but the time of making the stroke is proportionally less, so that upon the whole the effect is the same. The resistance opposed to the boat multiplied by the length of the oar beyond the boat, being, in either case, equal to the muscular power applied multiplied by the whole length of the oar, or rather to that length as measured to the point which forms the centre of resistance.

(274.) The next method in point of simplicity, and which, although differently arranged, is the same in principle, is the paddle wheel, which was applied to the propelling boats, long before it was thought possible to give motion to those paddles by the power of steam. The principal disadvantage of this application, as compared with the former is, that as the paddle or oar now makes a complete revolution, a part of the motion is lost, not merely by becoming non-effective, but by actually offering a retarding force, tending to check the forward motion of the boat, by each paddle lifting a quantity of water on its quitting the surface. A great deal of power is thus spent in the modern steam boat, where the actions and counteractions of the paddles are so mixed and confused one with the other, that it is perhaps wholly impossible, or at least extremely difficult to separate them, and thereby theoretically to compute the effect of a given steam power in propelling forward any vessel to which it is applied. If there were no back water, and the water itself could be preserved in the quiescent state always supposed in theory, we ought to find the product of the power applied to the pistons of a steam vessel, multiplied by the space through which they pass, equal to the resistance against the paddle or paddles acting in the water, multiplied by the space through which they pass in the same time, the piston power being supposed, as it is always understood in practice, to be the power remaining after the friction and other resistances of the engine have been deducted; and these products ought again to be equal to the resistance opposed to the boat multiplied by the space through which the boat advances during each stroke of the piston. It is in vain, however, to look for these equalities in practice, the quantity of back water, the resistance of the water within the paddle box, the extraordinary commotion of the water in the immediate vicinity of the wheels, are all actions of that kind, which resist and counter-resist the wheels, the vessel, and each other, in forms and degrees of so complicated a description, as to set at defiance any effort to separate them. We have, therefore, no intention to make the attempt, but by a comparison of several well-conducted experiments, to obtain results more simple and satisfactory, and more deserving of confidence than could possibly be deduced from the most refined analysis. Before, however, we enter on this part of the subject, it may be proper slightly to mention other methods which have been proposed for effecting the same object, that is, for propelling boats and other vessels in canals, rivers, and other streams.

(275.) Of these, one method consists of a combination of parts to be kept constantly under water, and to shut up into a small space when they are moved forward, but to expand when striking backward. Another consists of inclined planes placed behind the vessel, and moved with an alternating motion, as in the case of sculling.

Again, Daniel Bernoulli proposed, in 1752, a method consisting of planes immersed in the water, parallel to

the sides of the vessel, which, turning in a collar, were to be moved in a plane perpendicularly to the keel, and thus to urge the vessel forward.

Another contrivance is a screw, resembling what is called the water screw, working in a cylinder entirely immersed in the water, or two screws or spirals working in opposite directions without a cylinder. This method was partially tried by Mr. Whytock, and is alluded to by Colonel Beaufoy, who states it to have been brought from China, and he attended to see an experiment with it on a considerable scale, made in the Geenenland Dock by Mr. Littleton. This gentleman caused to be fixed to the stern post of a Virginia pilot boat a frame containing a large copper spiral, which was worked by a winch, turned by two or more men, to give it a rotary motion; but the effect was much less than was expected; for, notwithstanding the boat was completely empty, and great exertions made, the progressive velocity did not exceed the rate of two miles per hour.

Lastly, a method, to which we have before alluded, was a pump to draw water in in front, and to propel it out behind the vessel. This was first proposed by Bernoulli, and afterwards formed the ground of a patent taken out by Mr. Linaker, but it did not succeed. These, with numberless variations and combinations of the same principles, have been proposed with the same object, but it would be useless to enter into further description. Considerable experience has now shown, that of all the methods of propelling vessels, that of oars, where manual agency is employed, and paddles where steam is the motive power, are by far superior to any others yet suggested, although it is of course impossible to say what may yet be effected by the ingenuity of Man. If we could prove that the whole agency of the steam engine was employed in overcoming the resistance of the vessel only, we should know that all had been effected which was possible; but there is unquestionably at present a great deal of power thrown away, and great room is left for the exercise of ingenuity. This has, indeed, been sufficiently prolific, in the number and variety of shapes given to paddle wheels, in order to avoid some of the evils pointed out above; but, unfortunately, many of these, which are actually in other respects calculated to effect their object in a greater or less degree, are necessarily so complicated, and contain so many joints and moving parts, as to render them easily disarranged, while they possess too little strength to resist the enormous shocks a paddle wheel has to sustain in rough and stormy weather.

(276.) It has been already observed, that the extraordinary commotion of the water in the vicinity of the paddle wheel of a steam boat is such as to bid defiance to any investigation founded on theoretical principles only, and that the only means of arriving at the requisite data, is through the medium of experiment; fortunately, the writer of this Paper has been furnished with a series of results made at Woolwich, many of which he himself witnessed, on several of his Majesty's vessels, which seem to supply all the information that can be expected on this subject.

Generally, the navy steam vessels have their engines put in and their repairs made at Woolwich dock-yard; and every vessel before she leaves this station, is submitted to experiment. In one of the reaches of the Thames, near Purfleet, an English mile is measured on the bank, and two marks are placed at each end, so that as the boat runs down the river, it is an exact mile be

Experi-
ments on
steam ves-
sels.

Manufactures.

tween the points in her passage, where the two marks at each end cover each other. The time employed in running this mile is carefully noted by a seconds' watch; the vessel proceeds about a mile or a mile and a half further, is then put about, the mile is run the contrary way, the time again noted, and the experiment is frequently repeated a second or third time. This is commonly done about the time of high water, when there is but little tide; but the effect of this, whatever it may be, is always eliminated by means of the following equations.

Let t be the time in seconds in performing the mile against the tide;

t' the time with the tide;

v the velocity in miles per hour of the boat;

v' the velocity of the tide water;

n the number of seconds in an hour;

$$\begin{aligned} \text{then } \frac{t}{n}(v-v') &= 1 \\ \text{and } \frac{t'}{n}(v+v') &= 1 \end{aligned} \quad \left\{ \begin{array}{l} \text{or} \\ \end{array} \right. \quad \begin{aligned} t(v-v') &= n \\ t'(v+v') &= n. \end{aligned}$$

Multiplying the upper equation by t' , and the lower by t , we have

$$t t' v - t t' v' = t' n$$

$$t' v + t t' v' = t n,$$

by addition,

$$2 t t' v = n (t' + t);$$

whence

$$v = \frac{t' + t}{2 t t'} n.$$

The following experiments on his Majesty's steam vessel *Dee*, will illustrate this formula. Power 200 horses; twenty-three strokes per minute.

		m.	s.	s.
1. Exp.	Time of running a mile against the tide	5	51	or 351
	Ditto with the tide	5	33	or 333
2. Exp.	Time of running a mile with the tide	4	23	or 263
	Ditto against the tide	7	58	or 478
3. Exp.	Time of running a mile with the tide	4	50	or 290
	Ditto against the tide	6	35	or 395

$$1. \text{ Exp. } v = \left(\frac{351 + 333}{2 \cdot 351 \cdot 333} \right) 3600 = 10.52 \text{ miles per hour.}$$

$$2. \text{ Exp. } v = \left(\frac{263 + 478}{2 \cdot 263 \cdot 478} \right) 3600 = 10.58$$

$$3. \text{ Exp. } v = \left(\frac{290 + 395}{2 \cdot 290 \cdot 395} \right) 3600 = 10.76$$

$$3 / 31.86$$

$$\text{Main speed } 10.62$$

In this way the actual speeds of the several vessels in the following Table have been determined, and with it is also stated all the particulars necessary for investigating the laws in question.

Table of experiments. (277.) TABLE of Experiments to ascertain the Speed of the following Steam Vessels, in which is also stated the Power of the Engines, the Diameter of the Wheels, the Size of Paddle, Number of Strokes of the Piston, &c., made by O. Lang, Esq.

Names of Vessels.	Ton- nage.	Horse power.	Chaldrons of coals on board.	Stores.	Diam- eter of wheel.		Length of paddle.		Depth of paddle.		Immersion of paddle.		Number of strokes per minute.	Diam- eter of cylind- er.	Length of stroke.		Speed miles per hour.
					Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.			Inches.	Ft.	In.
Alban	294	100	14	None.	13	0	9	0	1	6	Not known.		27	40	3	6	8.84
Messenger	730	200	60	{ Channel service. }	19	4	10	0	2	0	..		20½	53¾	5	0	9.75
Messenger	730	200	130	Ditto.	19	4	10	0	2	0	..		18	..	5	0	8.0
Pluto	365	100	14	None.	14	4	9	0	1	10	1	9	26½	40	3	6	10.15
Hermes	730	140	130	{ Channel service. }	17	6	9	0	2	0	Not known.		18	44	4	6	6.3
Meteor	296	100	8	Ditto.	13	0	9	0	1	6	1	6	32	40	3	6	9.0
Firebrand	494	140	10	None.	17	0	9	0	2	0	2	4	24	44	4	6	10.15
Firebrand, Morgan's wheels.	494	120	12	{ Channel service. }	14	6	Diam. polygon.		2	11½	2	11½	28	42	4	0	10.55
Flamer, Morgan's wheels...	494	120	15	None.	13	0	Ditto ditto.		3	11½	3	11½	27	42	4	0	10.9
Carron	294	100	8	None.	13	0	9	0	1	6	1	4	28	40	3	6	9.15
Carron, Galloway's wheels..	294	100	8	None.	17	0	Not known.		3	2	3	2	22½	40	3	6	8.33
Dee	710	200	30	None.	19	4	10	0	2	0	1	6	23	53¾	5	0	10.61
Rhadamanthus	820	220	46	None.	20	4	9	0	2	6	Not known.		20	55½	5	0	10.39
Salamander	820	220	210	{ Channel service. }	20	4	9	0	2	6	5	6	15	55½	5	0	8.15
Firefly	550	140	152	Ditto.	17	6	9	0	2	0	3	4	20	44	4	6	8.3
Magnet	360	140	6	None.	16	0	10	0	1	6	1	8	29½	44	4	6	11.75
Phoenix	820	220	12	None.	20	4	9	0	2	6	2	6	21	55½	5	0	11.7
Medea, Morgan's wheels...	840	220	15	None.	21	0	{ Of the polygon area of paddle 21 ft. }		3	11	3	11	23	55½	5	0	11.33
Columbia, Morgan's wheels.	360	100	80	{ Channel service. }	14	0	{ Of the polygon area of paddle 11.85 }		1	10	1	10	24	40	3	6	8.5
Firebrand, Morgan's wheels.	494	120	40	Ditto.	14	6	Diam. polygon.		3	7	3	7	27	42	4	0	10.1
Flamer, Morgan's wheels, second experiment.....	494	120	112	{ Channel service. }	13	0	Ditto ditto.		5	6	5	6	24	42	4	0	9.57

NOTE.—The wheels distinguished as *Morgan's Wheels* are of a particular construction, by which the paddle is made to enter the water nearly perpendicularly, and leave it also in a like position; thereby avoiding the shock otherwise caused by the paddle striking the water on its entrance, and the back water thrown up by the common wheel on its exit.

These paddles are not always rectangular, but frequently of the shape shown in the annexed figure, and they turn on an axle in the line $a b$, which generally about bisect their area, and on which line the centre of pressure may be supposed to be situated, as they pass nearly perpendicularly through the water; whereas the common paddle, passing through the water circularly, different parts of it move with different velocities, which bring the mean centre of action below the middle. Moreover, the more

Machinery

Manufactures. remote parts act longer than those nearer the centre of motion, which brings this centre still lower. Calculation makes this point divide the depth of the paddle in the ratio of sixty-two to thirty-eight: but it will be enough for our purpose to take the ratio as three to two; and according to this proportion, the effective diameters of the several wheels given in the preceding Table, are computed and inserted in the following Table; at least in all the common wheels. Those of Morgan's construction, from what is above stated, require no reduction. Machinery

In this Table is also shown the tonnage per horse power; the area of paddle per horse power; the relative velocity of the boat, the paddle, and piston; and the computed horse power employed in propelling one vertical paddle in each wheel, and the proportion of the whole power of the engines expended on the paddles.

(278.) Table of Proportional Numbers deduced from the preceding Data.

Names of Vessels.	Ton- nage.	Horse power.	Tons per horse.	Area of paddle per horse.	Depth of paddle.	Effective diameter of wheels.		Ratio of velocity of wheel and pis- ton.	Ratio of velocity of vessel and pis- ton.	Ratio of velocity of vessel and wheel.	Ratio of the whole power to that on one paddle in each wheel.
						Ft.	In.				
Alban.	294	100	2.94	.27	1 6	12	0	5.4	4.1	.74	6.9
Messenger	730	200	3.65	.20	2 0	18	0	5.6	4.0	.73	5.7
Ditto	730	200	3.65	.20	2 0	18	0	5.6	3.9	.69	5.6
Pluto	365	100	3.65	.34	1 10	13	2	5.9	4.8	.82	6.6
Hermes	730	140	5.21	.25	2 0	16	2	5.6	3.4	.72	3.2
Meteor	296	100	2.96	.27	1 6	12	0	5.4	3.5	.65	2.3
Firebrand	494	140	3.51	.25	2 0	15	8	5.4	4.1	.76	4.9
Carron	294	100	2.94	.27	1 6	12	0	5.4	4.1	.76	6.3
Dee	710	200	3.55	.20	2 0	18	0	5.6	4.1	.72	3.8
Rhadamanthus	820	220	3.66	.204	2 6	18	8	5.9	4.5	.78	7.5
Salamander	820	220	3.66	.204	2 6	18	8	5.9	4.8	.80	18.0
Firefly	550	140	3.93	.245	2 0	16	2	5.6	4.1	.72	5.8
Phoenix	820	220	3.66	.204	2 6	18	8	5.7	4.5	.83	12.0
Magnet ...	360	140	2.57	.214	1 6	15	0	5.3	3.9	.74	6.0
Firebrand, Mor. wheels .	494	120	4.11	.212	..	14	6				
Flamer, Morgan's wheels	494	120	4.11	.220	..	13	0				
Flamer, 2d Exp. ditto. .	494	120	4.11	.220	..	13	0				
Medea, ditto.	820	220	3.66	.172	..	21	0	6.7	4.4	.66	1.9
Columbia	360	100	3.60	.237	..	14	0	6.2	4.3	.70	4.2

Law of re-
sistance de-
termined.

(279.) Before attempting any deduction from this Table, it may be well to report another experiment made in the basin in Woolwich yard, on the Medea, while at her moorings. In this case, the steam being admitted upon the piston, and both wheels connected, the number of revolutions per minute was found to be $8\frac{1}{2}$; one wheel being now put out of action, the power of the two engines, that is, the same power as before, was applied to one wheel only, and the number of revolutions per hour was found to be $12\frac{1}{2}$.

Here the power expended in these two cases is evidently as the number of revolutions, and therefore the power required to move a surface a , at the rate of $12\frac{1}{2}$, is to the power requisite to move a surface $2a$, at the rate of $8\frac{1}{2}$, as $12\frac{1}{2}$ to $8\frac{1}{2}$. Let the resistance vary as the n^{th} power of the velocity; then calling $12\frac{1}{2} = V$ and $8\frac{1}{2} = v$,

$$2a v^n = \text{resistance on both paddles,}$$

$$a V^n = \text{resistance on one paddle;}$$

but in the former case the resistance is overcome with the velocity v , and in the latter with the velocity V ; therefore the whole expressions of the two effects are

$$2a v^{n+1} \text{ and } a V^{n+1};$$

but these are to each other as the forces expended; viz. as $v : V$: we have therefore

$$2a v^{n+1} : a V^{n+1} :: v : V$$

$$2a v^n = a V^n;$$

hence

$$n \log v + \log 2a = n \log V + \log a;$$

$$n = \frac{\log 2a - \log a}{\log V - \log v} = \frac{\log 2}{\log V - \log v}.$$

Substituting the numbers, we find $n = 1.8$; or the power very nearly as the square, as the theory requires. Moreover, in one case, the friction of the wheels on their axles, and of the several joints in the different parts, (of which there are more than forty in wheels of this construction,) is double in one case what it is in the other; so that if we knew what allowance to make for this retarding force, we might find n still more approximative to the index 2.

From this experiment we may then conclude, that notwithstanding the great commotion of the water in the vicinity of the paddle, the resistance on the paddle varies as the square of the velocity. The number of revolutions in this case not having been so great as in preceding experiments of a similar kind, led the engineers to expect something amiss; the cylinders were therefore uncovered and examined, and some packing was found displaced: this being corrected, and the experiment repeated on one wheel, the number of revolutions per minute was $15\frac{1}{2}$. The experiment was not tried on both wheels, but there can be no doubt if it had, the speed in this case also would have been found proportionally greater.

These $15\frac{1}{2}$ revolutions per minute being due to the engines in their best state, we may examine how much of the power of the engine can be accounted for by the resistance and velocity of the paddle.

Manufac-
tures.

Here $15\frac{1}{2}$ revolutions per minute, the wheel being 21 feet in diameter, is equal to 1023 feet per minute, or 17 feet per second. This velocity produces a resistance due, a fall of $\frac{172}{4g} = 4\frac{1}{2}$ feet.

The area of one paddle being 19, and a cubic foot of water weighing $62\frac{1}{2}$ pounds, we have

$$4\frac{1}{2} \times 19 \times 62\frac{1}{2} = 5343.7 \text{ pounds} = \text{resistance.}$$

Now this resistance is overcome with a velocity of 1023 feet per minute, and that on the piston, *i. e.* $165 \times 220 = 36,300$, with a velocity of 155 feet per minute, or their relative velocities are as 6.6 to 1; hence

$$5343.7 \times 6.6 = 35,268.4,$$

and

$$36,300 \times 1 = 36,300;$$

that is, the whole force expended on one paddle is equal to the whole force of the engines, within one thirty-sixth part of the latter, which is probably due to the friction of the wheel as above stated. Hence then we may conclude, that in Morgan's wheels only one paddle in each is effective, the vessel being moored, and that the reaction upon it is equal to the power of the engine at that time exerted, or very nearly so.

(280.) We may now explain the computation by which numbers in the eleventh column of the preceding Table were obtained.

Method of
obtaining
the propor-
tional num-
bers in the
preceding
Table.

It is assumed, that the pressure of the engine for each horse power is 165 pounds, and consequently 165, multiplied by the number of horses, is the whole pressure on the engines. Also, from the last experiment, that the pressure of one vertical paddle is equal to the pressure due to the difference of the velocities of the paddle and boat into the area of the paddle. Now denoting the latter pressure on two paddles, one in each wheel, by p , that of the piston by P , and the ratio of the velocities of the paddle and piston by $r : 1$, then the ratio of the power exerted by the engine on a single vertical paddle in each wheel, is to the whole power of the engines as $p r : P$, and the latter divided by the former give the number contained in the last column.

As an example, take the case of the Albion.

As $7 : 22 :: 12 : 37.7$ feet circumference,

$37.7 \times 27 = 1018$ feet per minute, velocity of paddle,

8.84 miles per hour = 778 feet per minute, velocity of boat,

240 feet per minute = 6 feet per second,

the difference of velocity per second, or the velocity with which a vertical paddle acts upon the water, expressed by $V - v$. Now the pressure due to this velocity on any area a , is equal to that area multiplied by the weight of a column of water on the same base or area a , through which a heavy body must fall to acquire that velocity, which by the known laws of gravity, and the weight of a cubic foot of water, is expressed by

$$\frac{(V - v)^2}{4g} \times 62\frac{1}{2} \times a = \text{pressure.}$$

In the case in question, $v = 6$, $g = 16\frac{1}{2}$ feet, $a =$ area of two paddles = 27. Therefore

$$\frac{36}{64\frac{1}{2}} \times 62.5 \times 27 = 421.$$

Hence as $r = 5.4$, in this particular case,

$$\frac{165 \times 100}{421 \times 5.4} = 6.9,$$

Machinery.

which is the number in the Table; and it expresses, that of the whole power of the engines only about one-seventh of it is expended on two vertical paddles, one in each wheel.

In examining the numbers in this last column, considerable disagreement will be found to exist amongst them, which at first sight seems to defy all attempts at establishing any law by their aid. But it will be seen by the preceding computation, that the amount of this expression depends greatly on the value of the quantity $V - v$, the difference of velocity between the wheel and the vessel, and this difference depends much upon the number of strokes made in a minute. Now the gentleman who superintended these experiments made the register of the number of strokes per minute, without any idea of their being likely to be called for as an important part of his observations. No attempt was therefore made to state the fractional part of a stroke, and indeed no very minute attention was paid to the subject. It is obvious, however, that a fractional part of a stroke per minute will largely affect the numbers in question. We therefore propose now to reverse the operation, and by assuming six for a mean number in the last column, compute the corresponding number of strokes in the engine requisite to produce it; and it will then be found that a slight correction in the strokes of the engine will be sufficient to reconcile all these apparent anomalies.

Since we have seen that

$$(165 \times \text{horse power}) + \frac{(V - v)^2}{64} \times 62\frac{1}{2} \times a \times r = \text{No}$$

we have conversely, taking $\text{No.} = 6$,

$$\frac{64 \times (165 \times \text{h. p.})}{6 \times 62\frac{1}{2} \times a \times r} = (V - v)^2.$$

And since v , the velocity of the boat in each case, is given, that of V becomes known, and hence the number of strokes per minute. This computation is made, and the resulting number of strokes, and the registered number, entered in the two adjacent columns; and it will, we think, be readily admitted, that the corrections are not greater than are fully admissible under the circumstances in which this datum was recorded. Moreover, the wind has an influence which cannot be eliminated as can that depending on the tide; and which, independently of any want of precision in registering the strokes of the engine, would account for the discrepancies in question.

	Registered strokes per minute.	Computed strokes per minute.
Alban	27	27.6
Messenger . . .	20.5	20.6
Ditto	18	17.9
Pluto	26.5	27.1
Hermes	18	16.0
Meteor	32	28.0
Firebrand	24	23.6
Carron	28	28.3
Dee	23	21.8
Rhadamanthus	20	20.5
Salamander . . .	15	17.0
Firefly	20	19.1
Phoenix	21	22.6
Magnet	29.5	28.0

Manufac-
tures.

These differences, as above stated, are generally within the limits of one stroke per minute, except in one or two cases, where the vessel was deeply laden, and in the Meteor which is not laden. The discrepancy in the loaded vessels may depend, and it indeed must depend, on their greater immersion; the wind, moreover, has a considerable effect in retarding or accelerating the motion. So that on the whole, perhaps, we may be allowed to conclude from the preceding experiments, that, in general, only about one-sixth part of the power of the two engines is expended upon overcoming the resistance of the two vertical paddles one in each wheel.

It hence appears, that in the basin, with Morgan's wheels, all or nearly all the power expended by the engine is accounted for by the resistance of one paddle, when one wheel only is employed, and on two when two are in action. But that with the common wheels, and while the boat is in motion, and both wheels acting, the resistance experienced by one vertical paddle in each wheel will not absorb, at a medium, more than one-sixth of the whole power of the engines. These are results drawn from actual experiment, and no explanation or theory of the action of paddle wheels will be considered sufficient that is not competent to account for this apparent discrepancy, which must appear the more extraordinary as there can never generally be more than three paddles acting on each wheel at the same time, and as the vertical position of the paddle has been hitherto considered the most effective.

Question
respecting
the most
efficient
paddle exa-
mined.

(281.) This last supposition is, however, extremely erroneous; and acting on this error, or at least overrating the advantage of a direct action, many persons have endeavoured to make the paddles, by various contrivances, pass through the water in a vertical position, which, though it possesses some advantages, is the most unfavourable for propelling the boat through the water.

To demonstrate this fact, let the paddle form with the vertical an angle denoted by x . Let V be the circumferential velocity of the mean acting centre of the paddle, and v the velocity of the boat; then $V - v$ will be the relative velocity of the paddle and boat, when the former is vertical, and $V - \cos x v$ the relative velocity of the paddle and boat, in a direction perpendicular to the motion of the former, when the paddle forms with the vertical the angle x ; and since the resistance is as the square of the relative velocity, the perpendicular resistance to the paddle in this position will be as $(V - \cos x v)^2$; and as this resistance is overcome with a velocity V , the whole effect of the paddle in this position is $(V - \cos x v)^2 V$.

But this resistance is perpendicular to the face of the paddle, and must therefore be resolved into two forces, one horizontal, which is wholly effective in propelling the boat, and the other vertical, which is wholly ineffective. This resolution gives

$$(V - \cos x v)^2 V \cos x = \text{effective force,}$$

$$(V - \cos x v)^2 V \sin x = \text{non-effective force;}$$

which, in the vertical position of the paddle, when $x = 0$, becomes

$$(V - v)^2 V = \text{effective force,}$$

$$0 = \text{non-effective force;}$$

because, in this case, $\sin x = 0$, and $\cos x = 1$.

To find the angle x when $(V - \cos x v)^2 V \cos x = a$ maximum, we have only to make its differential equal to zero, whence

$$0 = -2V \cdot d(\cos x) (V - \cos x v) V \cos x + V d \cos x (V - \cos x v)^2 \quad \text{Machinery.}$$

which reduced gives $\cos x = \frac{V}{3v}$.

The angle, therefore, at which the effective force is a maximum, depends upon the relative velocity of the paddle and the boat.

$$\text{If } V = 3, v = 2, \text{ then } \cos x = \frac{3}{6}, \text{ or } x = 60^\circ.$$

$$\text{If } V = 4, v = 3, \text{ then } \cos x = \frac{4}{9}, \text{ or } x = 63^\circ 38'.$$

$$\text{If } V = 5, v = 4, \text{ then } \cos x = \frac{5}{12}, \text{ or } x = 65^\circ 23'.$$

And by substituting these values of cosine x in these three cases, it will be seen how much the effective power of the paddle in its best position exceeds its effect in the vertical position. Thus

$$\text{Case 1. } \begin{cases} \text{Force on vertical paddle} = 3 \\ \text{At the angle } x = 60^\circ \text{ ditto} = 6 \end{cases}$$

$$\text{Case 2. } \begin{cases} \text{Force on vertical paddle} = 4 \\ \text{At angle } x = 63^\circ 38' \text{ ditto} = 12.8 \end{cases}$$

$$\text{Case 3. } \begin{cases} \text{Force on vertical paddle} = 5 \\ \text{At angle } x = 65^\circ 23' \text{ ditto} = 23.1 \end{cases}$$

These angles, however, which give the maximum effect exceed those at which the paddle meets the water in most practical cases, although in deep laden vessels the wheel is sometimes so much immersed, that the paddles do actually meet the water when forming an angle of 60° with the vertical, as is the case with the Salamander in the preceding Table of experiments; but, in general, about one-fourth the extreme circumference of the wheel may be supposed to be immersed, and then of course the paddle meets the water when at an angle of 45° .

(282.) It is not easy to find the sum of all the actions of a paddle, while passing through the water, because, in the beginning of its action, it is not wholly immersed, and a similar defect takes place at its exit; so that properly we ought to find the sum of all its actions from its first immersion until it is wholly immersed, and then the sum of its actions when wholly immersed; but this is a degree of precision which the uncertain amount of immersion would hardly require in such a case as the present. Our object will, perhaps, be sufficiently attained by considering the paddle as wholly immersed at the angle of 40° , and then to compute its effect while passing through an angle of 80° , as if it were wholly immersed through this arc.

To effect this, and at the same time to find the amount of all the non-effective forces, we must find the sums of the two following differential expressions, viz.

$$\int (V - \cos x v)^2 V \cos x dx = \text{effective force,}$$

$$\text{and } \int (V - \cos x v)^2 V \sin x dx = \text{non-effective}$$

It is not necessary for us to pursue this subject; enough has been done to show that the vertical position of the paddle is that in which it is least effective, and that where a wheel is so constructed, as that all its paddles shall act vertically, it is necessary to make that paddle larger than in the usual wheel, or to make the wheel revolve with a greater relative velocity in respect to the vessel. But every unnecessary increase of velocity absorbs a proportional quantity of steam, which is lost in effect as a propelling power, and, therefore, although

To find the
mean ac-
tion.

Manufactures.

with such a paddle, there is no non-effective mechanical resistance, the increased velocity of the wheel absorbs a quantity of power equal to or closely approximating to that which is expended with the common wheel in overcoming the non-effective resistances to which the paddles are in this case exposed. It is true that the increased velocity may be obtained by enlarging the diameter of the wheel without increasing the speed of the piston, and therefore without a greater supply of steam; still, however, the fact remains the same, that with the same area of paddle and diameter of wheel, the constantly vertically acting paddle must revolve with greater velocity than the common wheel to propel the vessel with equal speed.

Proportional effective and non-effective resistance.

(283.) In order to compute what part of the power of an engine is employed in propelling the vessel, and what part is expended in urging the paddle through the water backward, we shall first endeavour to simplify the conception of the operation, by referring to the case of a boat when being rowed. Conceive a boat with a square end whose section is a , and an oar with a square flat section, or, which is the same, conceive the end of the oar, instead of having such a square face, to be placed in another boat equal to the former, and both free and floating in still water; then a force being applied to the oar, both boats will offer equal resistances, and being equal, both will take up equal velocities, and half the whole force will be employed in giving the two motions. But if the area of one boat be A , and the other a , the velocities they must take up to produce equal resistances will be inversely as the square root of A and a ; that is, the resistance being as the square of the velocity, we must have $A v^2 = a v'^2$.

But the resistance $A v^2$ being overcome with a velocity v , and $a v'^2$ with a velocity v' , the actual forces employed in the two cases will be as $A v^3 : a v'^3$, or as $v : v'$; because $A v^2 = a v'^2$. To determine all the circumstances, therefore, we have the following equation, P being taken to represent the power or pressure on the oar, and w its velocity, viz.

$$\begin{aligned} A v^2 &= a v'^2 \\ A v^3 + a v'^3 &= P w. \end{aligned}$$

But the velocity w is dependent on the sum of the velocities $v + v'$, according to the length of oar or lever within and beyond the boat: let this ratio be $1 : r$, then

$$w = \frac{1}{r} (v + v');$$

wherefore

$$\begin{aligned} A v^2 &= a v'^2 \\ A v^3 + a v'^3 &= \frac{P}{r} (v + v'). \end{aligned}$$

Or if we make $v + v' = V$, then $v' = V - v$, the above become

$$\begin{aligned} (V - v)^2 a &= V - v^2 A \\ (V - v)^3 a + v^3 A &= \frac{1}{r} V \cdot P. \end{aligned}$$

In this form the equations become applicable to the case of steam vessels; V being the velocity of the wheel at the point of pressure, or the velocity with which the paddle and boat are separated from each other, v the velocity of the boat, and $V - v$ the velocity of the paddle through the water; a the area of all the acting paddles, and A the area of a square section, which would at the same velocity offer the same resistance as the action of the vessel submerged in the water. P the pressure on the pistons of the engines, and

$$r = \frac{3.1416 \cdot \text{diam. wheel,}}{2 \cdot \text{stroke of piston.}}$$

Machinery

If the pressure P is stated in pounds, then the resistance must also be stated in pounds. In this case the resistance

on the paddle is $(V - v)^2 a \times \frac{62\frac{1}{2}}{4g}$, g being equal to $16\frac{1}{2}$, the force of gravity, and $62\frac{1}{2}$ the weight of a cubic foot of water in pounds, and, therefore, the actual equations then are

$$(V - v)^2 a = v^2 A,$$

as before, and

$$\frac{62\frac{1}{2}}{4g} (V - v)^2 a + \frac{62\frac{1}{2}}{4g} v^2 A = \frac{VP}{r};$$

consequently, since $(V - v)^2 a = v^2 A$, the power $\frac{VP}{r}$

is divided between the paddle and vessel, in the proportion of $V - v : v$. When, therefore, as is generally the case in the vertically acting paddles, $V : v :: 3 : 2$, one-third of the whole power of the engines is expended on the paddles; whereas, in the other cases, viz. the common wheels, only one-fourth or one-fifth is thus lost; but to this must of course be added the loss from non-effective action as expressed in the preceding equations, (Art. 281.) which latter will, from the nature of the equation, be proportionally more as the vessel is more deeply laden; and this result is perfectly consistent with those drawn from the experiments in the foregoing Tables.

(284.) We cannot pursue this subject further in this place, but the reader, who is desirous of entering fully into the investigation, is referred to a Paper *On the Laws which govern the Motion of Steam Vessels*, in the *Phil. Trans.* 1834, part ii. by P. W. Barlow; we can only here state the results of the author's investigation, viz.

1. That when the vessels are so laden that the wheel is but slightly immersed, there is little advantage in the vertically acting paddle.

2. In cases of deep immersion, it has considerable advantage over the common wheel, as at present constructed.

3. That in the common wheel, while the paddle passes the lower part of the arc, or when its position is vertical, it not only affords less resistance to the engine, but is less effective in propelling the vessel than in any part of its revolution.

4. That in the new wheel, the paddle, while passing the lower part of the arc, affords more resistance to the engine, and is more effective in propelling the vessel, than in any part of its revolution.

This property of the vertical paddle is a serious deduction from the value of the wheel; for in consequence of the total resistance to all the paddles being so much less than in the common wheel, much greater velocity is required to obtain the requisite pressure, which is attended with the consumption of an additional quantity of steam, and, in course, of a proportionate loss of power.

This loss of power is most sensible when the wheel is slightly immersed, as may be seen from the Table; whereas the lost power, from the oblique action of the common wheel, is then scarcely perceptible. When the vessel is more immersed, and the angle of inclination at which the paddle enters is greater, the proportion of

General laws of action.

large diameter, and the paddles too small, is very sensibly exhibited in the experiment on the Medea. Her engines have the same length of stroke as those of the Salamander, Phœnix, and Rhadamanthus, and the wheel is twenty-one feet in diameter to the centre of pressure, while those of latter vessels are not above eighteen feet five inches, or eighteen feet six inches. The consequence is a considerable loss of power, from the greater velocity of the wheel than of the ship, the whole power of the engine being brought out in both cases. This loss of power is, of course, still small, compared with that of the common wheel when deeply immersed, so that in the experiment at Sheerness, her superiority of speed is perfectly consistent with the preceding calculations; at the same time we have no hesitation in saying, that an increase of speed of half a mile per hour at least might be obtained by a smaller wheel and more surface of paddle board.

This view of the case is still further confirmed by experiments on the Monarch steam vessel. A former experiment on this vessel, not reported in the Table, with a wheel of less diameter and larger floats, gave a speed above eleven miles per hour. In the experiment given in the Table, the average velocity is 10.8, so that a sensible diminution of speed was produced by enlarging the diameter of the wheel.

(285.) *Proportions and Dimensions of several English Steamers.*

The following list of the proportions of steam vessels, their tonnage, powers, dimensions of cylinders, length of stroke, and other particulars, will illustrate the practice of some of the best engineers, and the several proportions adopted by them. We give also the following particulars of the American steamer, the De Wit Clinton, by which it will be seen how much our Transatlantic brethren exceed us in the dimensions of their vessels, and in the power of their engines.

De Wit Clinton Steamer.

Passage from New York to Albany, 150 miles in 9 hours 18 minutes; upper deck 233 feet; best cabin 175 feet; breadth water line 28 feet; draws 4 feet 6 inches water; 66 inch cylinder, double stroke 10 feet; 4 circular valves, $17\frac{1}{2}$ inches diam.; diam. paddle wheel 22 feet; wide 15 feet; depth not given; 37 floats; 26 strokes per minute; 4 iron boilers, one fore and one abaft of each wheel; 4 chimneys; steam 20 pounds on safety valve; expanded inch cylinder 10 pounds average; estimated pressure 12 pounds, deducting all friction; 646 horse power; shaft $14\frac{1}{2}$ inches wrought iron.

W. & A. G. Maudslay, Son, and Field, London.

8. That an advantage would be derived from a wheel of large diameter, so far as the immersion of the paddle produced by loading the vessel would not so sensibly affect the angle of inclination of the paddle ; this, however, cannot be attained advantageously with an engine of the same length of stroke, because to allow it to make its full number of strokes with the large wheel, the size of the paddles must be diminished, which is a much greater evil than a wheel of small diameter with larger paddles. To have larger wheels, it is therefore either necessary to have the engines made with longer strokes, or to have the paddle wheel on a different shaft to the engine, in order to diminish their speed. These are both practical inconveniences in sea boats, and we must therefore consider the wheels to have gained their greatest limit in point of diameter. For the navigation of rivers, as the construction of the boats will admit of much greater speed given to them than is at present attained, larger wheels may be employed.

The ill effect resulting from making the wheel of too

[illegible]

TABLE continued.

Engine builders, Maudslay, Son, and Field, London.									
Name of the vessel.....	DEE.	ENTER-PRIZE.	COMMERCE.	BEURS VAN AMSTERDAM.	LONDON ENGINEER. Brent.	LIGHTNING.	HARLEQUIN.	IVANHOE.	CRUSADER.
Name of the builder of the vessel.....	700 tons	500 tons	400 tons	500 tons	315 tons	296 tons	232 tons	160 tons	95 tons
Tonnage (register)	200 h. p.	120 h. p.	140 h. p.	120 h. p.	70 h. p.	100 h. p.	80 h. p.	60 h. p.	50 h. p.
Total power of engines.....	..	..	..	..	630 pounds	1240 pounds	..	..	..
Velocity in still water.....	..	..	..	..	Wylemcoals	average	..	..	..
Coals per hour.....	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines
Engines, number	53 inches	43 inches	46½ inches	43 inches	36 inches	40 inches	36 inches	32 inches	29½ inches
Engines, diameter of cylinders ..	60 inches	48 inches	54 inches	48 inches	30 inches	48 inches	42 inches	36 inches	36 inches
Engines, length of stroke	20 strokes	24 strokes	22 strokes	25 strokes	28 strokes	25 strokes	28 strokes	30 strokes	32 strokes
Engines, strokes per minute	..	..	..	..	..	..	..	..	..
Engines, diameter of air pump ..	Navy	East Indies	Liverpool and Dublin	Amsterdam and London	Margate Packet	Navy	Post Office Packet	Post Office Packet	Post Office Packet
Used for.....	1827	1825	1826	1826	1818	1824	1824	1826	1827
Date of construction.....	272 h. p.	160 h. p.	197 h. p.	160 h. p.	88 h. p.	137 h. p.	104 h. p.	76 h. p.	68 h. p.
Calculated power of engines at the best velocity and full pressure.									
Engine builders, Boulton and Watt, Soho, Birmingham.									Fenton and Co., Leeds.
Name of the vessel.....	SOHO.	JAMES WATT.	CITY OF EDINBURGH.	SHANNON.	SOVEREIGN GEORGE IV.	CALEDONIA.	METEOR.	HERO.	
Name of builder of vessel	..	Wood & Co.	Wigram	Fletcher & Son	Evans	Wood & Co.	Evans	Bancham	
Length of deck	163 feet	146 feet	143 feet	180 feet	126 feet	95 ft. 6 in.	20 feet	..	
Breadth (extreme)	27 feet	25 ft. 8 in.	25 ft. 6 in.	49 feet	21 ft. 10 in.	15 ft. 0 in.	..	..	
Draught of water	..	10 ft. 0 in.	..	..	8 ft. 6 in.	4 ft. 6 in.	..	6 ft. 4 in.	
Paddle wheels, diameter	15 ft. 8 in.	18 ft. 0 in.	18 feet	..	16 feet	..	..	14 ft. 0 in.	
Paddle wheels, breadth.....	8 ft. 0 in.	9 ft. 0 in.	8 feet	..	8 feet	..	8 feet	8 ft. 0 in.	
Paddle wheels, velocity of extremity in miles per hour ..	14.6 miles.	12 miles	12 miles	..	..	..	..	15 miles	
Paddles depth	2 feet	2 ft. 0 in.	2 feet	..	..	..	..	1 ft. 6 in.	
Tonnage (register)	510 tons	448 tons	400 tons	513 tons	210 tons	102 tons	190 tons	233 tons	
Nominal power of engines.....	120 h. p.	100 h. p.	80 h. p.	160 h. p.	80 h. p.	28 h. p.	60 h. p.	90 h. p.	
Velocity per hour in still water ..	..	10 miles	..	..	9½ miles	8½ miles	..	11½ miles	
Coals per hour.....	..	..	..	..	896 pounds	..	560 pounds	2240 pounds	
Engines, number	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	2 engines	
Engines, diameter of cylinders ..	42 inches	39 inches	36 inches	..	..	..	..	..	
Engines, length of stroke	48 inches	42 inches	42 inches	..	..	..	..	..	
Engines, strokes per minute	26 strokes	27½ strokes	27½ strokes	..	..	..	..	30 strokes	
Engines, diameter of air pump ..	23 inches	21 inches	19½ strokes	..	..	..	..	..	
Used for	Passengers	Passengers	Passengers	{ Passengers and 200 tons goods }	Post Office Packet	..	Post Office Packet	Margate Packet	
Date of construction.....	1823	1821	1821	1826	1821	1815	1821	1821	
Calculated power of engines at the best velocity and full pressure	151 h. p.	122 h. p.	104 h. p.	..	..	..	..	..	
Engine builder, Napier, Glasgow.					Engine builders, Faucett & Littledale, Liverpool.				
Name of the vessel	UNITED KINGDOM.	MAJESTIC.	SUPERB.	TALBOT.	ST. PATRICK.	PRINCE LLEWELLYN Notchershead	ALBION.	DUKE OF LANCASTER, Hayes.	CAMBRIA.
Name of builder of vessel	..	Scott & Co.	Scott & Co.	Wood & Co.	..	..	..	..	..
Length of deck	175 feet	..	..	92 feet	130 feet	..	103 ft. 6 in.	103 feet	91 ft. 2 in.
Breadth (extreme)	45 ft. 6 in.	..	..	17 ft. 11 in.	20 ft. 1 in.	..	18 ft. 1 in.	17 feet	17 ft. 6 in.
Draught of water	..	..	..	..	13 ft. 8 in.	..	9 ft. 6 in.	9 ft. 6 in.	8 ft. 4 in.
Paddle wheels, diameter	..	..	..	..	..	..	..	..	..
Paddle wheels, breadth.....	..	..	..	..	..	..	..	..	..
Paddle wheels, velocity of extremity.....	..	..	..	..	..	..	..	..	..
Paddles, depth.....	..	..	..	..	..	..	..	..	..
Tonnage, (register).....	1000 tons	350 tons	241 tons	140 tons	200 tons	170 tons	103 tons	94 tons	86½ tons
Power of engines.....	200 h. p.	100 h. p.	70 h. p.	60 h. p.	100 h. p.	70 h. p.	60 h. p.	50 h. p.	50 h. p.
Velocity per hour in still water ..	..	10 miles	9 miles	..	..	..	..	..	..
Coal per hour	2240 pounds	2240 pounds	1670 pounds	784 pounds	..	..	..	..	..
Engines, number.....	2 engines	2 engines	2 engines	..	2 engines	2 engines	2 engines	2 engines	2 engines
Engines, diameter of cylinders ..	..	..	..	..	42 inches	..	32 inches	..	30 inches
Engines, length of stroke	..	..	..	..	42 inches	..	33 inches	..	30 inches
Engines, stroke per minute	..	28	..	..	..	..	..	..	..
Engines, diameter of air pump ..	..	..	..	..	..	..	..	..	..
Used for.....	Edinburgh packet, 175 passengers	..	..	Post Office Packet	..	..	..	..	..
Date of construction	1826	1816	1820	1819	1822	1822	1822	1822	1822
Calculated power of engines at the best velocity and full pressure	..	..	..	..	142 h. p.	..	73 h. p.	..	67 h. p.

Manufac-
tures.

Description of a Boat Engine of the usual form, and with a Vibrating Cylinder.

Pl. xix.
and xx.
Boat engine
described.

(286.) Plate xix. fig. 1 and 3, and pl. xx. fig. 2, are the plan and sections of his Majesty's steam ship *Phœnix*, of 820 tons burden, with two engines of 110 horse power each, by Maudslay. A A is the keel of the vessel, B B the main timbers, and C C the upper deck. In the part occupied by the engine and boiler, the vessel is clear from the upper deck down to the hold. Four timbers of great strength, D D D D, extend in a longitudinal direction from one end to the other, which support the engine and boiler. The great strength of these beams is of importance, in order to distribute the strain produced by the reaction of the engine over as great a surface as possible. In the *Phœnix* the engine is placed with the cylinder E E towards the head of the vessel; this arrangement has, however, been altered in the *Medea*, which has been since built, the engines being placed with their cylinders to face the boiler or stern of the vessel. This has the effect of throwing the main shaft of the paddle wheels more forward, which is considered an advantage. F F are the boilers, of which there are four, placed together in such a manner that any number may be used as required. Three is the greatest number required when a vessel is using its full quantity of steam; one being always ready for use in case any accident happens. The fire-places are now generally placed at the forward part of the boilers, as shown at *a a*. In some of his Majesty's vessels they have been placed in the after part of the boiler; or rather the boilers have been reversed, with a view of bringing the fire-places as near as possible to the coals contained in the coal boxes G G G, in order to avoid the labour of bringing them the length of the boiler: but this arrangement has not been found to answer in consequence of the want of air, which results from such a confined situation. In some vessels one half of the boiler has been turned one way and one half the other. This practice has also been discontinued, and they are all now used as shown in the plate.

The construction of the boilers is varied in vessels of different dimensions; sometimes they are made square, as shown in the drawing, sometimes to fit the shape of the vessel, or cylindrical. The fire circulates through flues which pass several times from one end of the boiler to the other, in order that as much heat as possible may be given out before the flame and smoke arrive at the chimney H H. The part marked I is a reservoir of steam, from which the steam is conveyed to the cylinder by the steam pipe S S. K K is the waste pipe through which the steam passes off from the safety valve.

The engine needs but little description, as it only varies from the low pressure engine used on land in the arrangement of the parts, to the circumstances in which it is placed. Each engine has two beams, *b b*, situated below the cylinder, one on each side, which are attached by side rods to a cross head on the piston rod. The parallel motion is effected by horizontal rods *c c*, attached at one end to a joint in the side rods of the beams, and at the other to a small crank, which, by its rotation, allows the deviation from the straight line which must occur to preserve the motion parallel. The other extremity of the beams are connected by a cross piece to which the crank rod is attached. The crank in

boat engines is generally a little varied from those used on shore in consequence of the sudden blow it is liable to from a sea striking the wheel, which would endanger breaking them off if they were connected by one pin passing through both. An intervening piece is, in consequence, introduced, termed the driving link, shown at *e*, fig. 2, which not only preserves the crank, but takes off the shock from the engine. Sometimes a drag link is used, which only differs from the above by being placed on the contrary side of the engine crank, so that it drags the other after it instead of driving it. The air pump is seen at *f*; it is worked by a cross head, with side rods connected to the beam; *d* is the slide valve which receives its motion from the eccentric *g* on the main shaft; *h* is the condenser, and *k* a cylindrical vessel which forms the hot well; its height being required to prevent the motion of the vessel from dispersing the water. In order to avoid confusion in the drawing, two parts of the engine have been omitted which it is necessary to mention, *viz.* the pump which supplies the boiler with water and the bilge pump; they are placed one on each side of the cross head of the air pump, so that their bucket rods work through a projected part of it, and can be put in gear when required by a screw in the cross head.

P P P is the paddle wheel; it has two bearings, one in the side of the vessel, and the other in the paddle box; *l l l* are small cast iron flanches or wheels attached to the shaft wheel, having mortises left in them to receive the wrought iron arms *m m m*, &c. These arms are further secured by flat wrought iron rings which are bolted to their extremities; and in the larger description of wheels, such as the present, an additional one, at about two-thirds of their length, is added. The arms of the wheel are generally made to radiate from the centre. In some wheels latterly constructed by Maudslay, they are, however, made to radiate from points at a little distance from the centre. This is done with the view of diminishing the angle with which they enter the water, in order to take off the shock from the engine, produced by the paddle floats striking the water at too obtuse an angle. The paddle boards are made of planking of about two inches in thickness, which are bolted to the arms by bolts, one end of which is provided with a hook which fits over the wrought iron arm, and the other passes through the board, and has two nuts, one above the other, which are found necessary from the great tendency they have to become loose from the jarring of the board.

Within a few years a paddle wheel upon a new principle has been applied to several Government vessels, termed Morgan's wheel. The object attained by it is to cause the paddles to enter the water in a position nearly vertical, instead of at an angle. This is found to prevent the injurious shock which is given to the engine by the floats of the common wheel, particularly when much immersed, and is also found in such cases to add to the speed of the vessel. A paddle whose action is always vertical, has long been considered desirable, and the inventions to effect this object have been very numerous, but have been generally so complicated, and attended with so much friction and liability to get out of order, that they have never been brought into general use. These wheels are certainly the most simple of the kind, but they are still attended with a liability to derangement, and consequent expense in repair, which materially affects their value.

Manufac-
tures.
Pl. xx.
Fig. 4.

Fig. 4, p. xx. represents the mechanism of the wheel; *aaaa*, &c. are the paddles which turn upon spindles, having a bearing in the angles of the framework of the wheel *b, b, b*, and which is of a polygonal figure, with as many sides as it is required to have paddles. The inside frame or polygon is alone attached to the shaft of the engine, which does not continue beyond the side of the vessel; and the outer one has an independent bearing on a centre attached to the paddle box, so that it receives its motion entirely from the rim or angles of the polygon; by this means the space between the sides of the wheel is left entirely free. The part marked B is a part of the shaft or centre upon which the outer side of the wheel revolves, projected in an inclined direction to the middle between the sides, but of course to a point considerably eccentric with the wheel.

Each paddle has a crank *c*, attached to it at an angle of nearly ninety degrees, and rods *d d d*, &c. connect the extremity of this crank with a movable boss which revolves upon the fixed point B.

It will thus be seen, that in consequence of the point B being situated out of the centre, the paddle will assume different positions during the revolution of the wheel, which positions can be so arranged as to differ very little from a vertical direction while passing the lower part of the revolution, or that part where the action of the paddle takes place.

This will sufficiently illustrate the principle of the action of the wheel. In the construction a variety of practical considerations, of course, require to be attended to, one of which it is, perhaps, necessary to mention, *viz.* that the piece B, to which the rods are attached, has motion given to it, otherwise they would not keep at their proper distances. This is effected by securing one of the rods, which is made stronger than the rest, firmly to the piece B. In this way the paddle, while its position is changed by the fixed rod or driving arm, gives it a rotation round the fixed point, and with it all the remaining movable rods of the wheel.

Maudslay's
vibrating
engine.
Fig. 5

(287.) *Maudslay's vibrating engine.*—Among the late improvements in steam boats may be mentioned the introduction of the vibrating engine by Maudslay, by means of which a saving of weight and expense of Machinery is effected, and at the same time a considerable space in the vessel is saved by its taking up less room than the beam engine.

Fig. 5 is an elevation of Maudslay's vibrating engine, which differs from those previously constructed, simply in the application of the slide valve, for which he has within a few years taken out a patent. A A A is strong cast iron framework which supports the hollow cylindrical axle in proper brasses at B, and the main shaft of the engine at its upper part. C C C is the cylinder, which is surrounded at D D by a hollow belt, one end of which is connected to the opposite hollow axle of the engine, and to the top and bottom of the cylinder, by means of flat pipes seen at F F. The slide valve C C is bolted to the cylinder between these pipes: it has two flanches upon it, *aa, bb*, which serve as a guide for the rods which give motion to the slide; the part of the slide valve casing marked *cc* is made smaller, in order to be able to get at the packing of the lower valve, which is effected by taking off the flanch *dd*. The manner in which motion is given to the slide will be sufficiently understood by the drawing, and, therefore, needs no further description. The interior construction of the valve and cylinder exactly resembles that of the

land engine. The action of the engine is as follows. Machinery. When making the down stroke, the steam enters the top of the cylinder by the hollow axle H and slide valve, while the bottom of the cylinder is open to the condenser by the flat pipes and hollow belt; the connection is of course reversed when the piston arrives at the bottom of the stroke.

When double engines are employed, as is usual in steam vessels, one air pump and condenser are placed between the two cylinders, the air pump being worked by the crank shaft which connects the two engines.

Several engines of this description have been fitted to small steam boats, and have been found to answer perfectly well; they have not, however, been at present used in the larger description of vessels.

Application of the Steam Engine to Inland Communication.

(288.) The inland traffic between different parts of a Country is of so much national importance, that it will be proper in treating of the locomotive engine, to take a general view of the progress which has been made in a comparatively short period in England in all her internal communications, to show also how much her greatness has increased, and how much it is dependent on facility of transport. With roads nearly impassable, she remained for many years a comparatively poor and feeble nation; the corn grown in one district could not be transferred to another without such an enormous expense of carriage as to act nearly as a prohibition. On the other hand, the transfer of raw materials served to raise the price of every kind of Manufactures, which were again subject to an additional expense if carried to the distance of some miles from the towns in which the goods were made: thus while one County could have supplied food to another, which would gladly have exchanged for it the cloth of its manufacture, as much wanted by the former as the corn by the latter, neither could assist the other in consequence of the almost insuperable obstacle opposed to conveyance. It is true that, being an island, surrounded on every side with seas and navigable channels, a communication was easily kept up along her coasts; and to this circumstance, in the early period of her rise, there is no doubt England was largely indebted for the comforts she then enjoyed. Some navigable rivers also extended these benefits inland to certain distances and to certain points, which points, however, for want of road conveyance, remained nearly isolated from each other; so much so, that weights, measures, and nearly every standard of comparison, were different in different Counties.

Such, we may say, was the state of England in the commencement of the XVIIIth Century: at that time the formation of turnpike roads began to be a favourite measure, both with the People and the Government; but the progress was slow, and so late as the middle of the last century, to travel more than forty miles a day was considered amongst the wonders of the time. The inhabitants of a County-town or city, at a distance of a hundred miles from London, seldom thought of any established conveyance by coach or otherwise to perform the journey in less than two days and two nights; indeed, the writer of this Essay remembers when the quickest conveyance between a large town, only a few more than one hundred miles from London, was the work of two long days and one night, a journey which is now performed regularly

Introductory remarks.

State of the English roads in 1700.

Manufac-
tures.

in twelve hours, and has been done in ten and a half, and which will, perhaps, soon be effected in much less time.

Such has been the effect of turnpike roads, of which we had in 1821, according to the Parliamentary Report, 24,531 miles spread over the Country, in different parts of England, Wales, and Scotland. Of these, 18,320 miles are in England, 2591 in Wales, and 3611 in Scotland.

Canal com-
munication.

(289.) Some years before the period last alluded to, a new stimulus had been given to inland communication, first by the establishment of the Mersey and Irwell Company, and secondly by the formation of the first British Canal by the Duke of Bridgewater, who, in 1758, obtained an Act of Parliament and set aside large sums to the prosecution of inland navigation, by which he not only realized a princely fortune, but may be said to have laid the foundation of his Country's commercial greatness. The advantage of Canal navigation at that time was enormous. On our best roads at that day the force of traction was certainly not less than one-eighth or tenth of the load and carriage, and when these were heavy the speed could not exceed two miles or two and a half miles per hour; whereas on a canal, the force of traction at that pace is not above a thousandth, or at the most one-nine-hundredth of the load. Here at once the force of traction was reduced to one-hundredth part of its original amount, and of course with advantage to places lying within the range of the Canal. An advantage so striking could not but be seized with eagerness by persons of foresight and fortune; and accordingly, in a few years after we find Great Britain penetrated with Canals in every direction, circulating and connecting her various points of product and consumption, distributing animation, conveniences, and luxuries through her extended surface, and, like the veins of the human body, giving health and vigour to the whole system.

(290.) Some idea of the immense increase of Manufactures which followed the above two early attempts at inland water communication, may be gathered from the following details, given by Mr. Booth in his Official Report relating to the Liverpool and Manchester Railway. In 1760, 2560 vessels paid dock duties at Liverpool; in 1824, 10,000; and in 1829, 11,383:—in 1760, the population of Liverpool was 26,000; in 1824, 135,000; the population of Manchester being, in 1760, 22,000, in 1824, 135,000:—in 1784, only eight bags of cotton were imported into Liverpool from America; in 1824, 409,670 bags; and in 1829, 640,998. In 1790, the first steam engine was set up in Manchester; in 1824, there were 200 steam engines there: in 1814, there was not one power loom in Manchester; in 1824, there were 30,000. In 1824, the average quantity of raw and manufactured goods transmitted between the two towns was 1000 tons daily, and it now amounts to 1300 tons; about 1000 of which pass from Liverpool to Manchester, and 300 from Manchester to Liverpool. The bulk of this immense traffic was carried by means of the two Canals before mentioned.

Even with these accommodations, goods had to be first sent up the River Mersey to Runcorn, a distance of about twenty miles, and thence by one of the two canals to Manchester, making the whole distance between the two towns about fifty miles. In Summer time there was frequently a deficiency of water, obliging boats to go only half loaded, while in Winter they were sometimes locked up with frosts for weeks together. Vessels, too, were often arrested in their progress up the Mersey

by contrary winds, and exposed to loss and damage Machinery. from tempestuous weather. The average length of the passage was thirty-six hours; but owing to the various causes of delay just enumerated, there have been instances of goods being a longer time on the way (by water) from Liverpool to Manchester than from New York to Liverpool!

The present length of Canal navigation, in England, Scotland, and Ireland, exceeds three thousand miles, which, ramifying in all directions from coast to coast, and penetrating our most inland districts, gives a facility of conveyance of every kind of material, wrought or unwrought, scarcely to be comprehended by those who have not paid particular attention to the subject. The barges in one place export corn and bring back manure; in another, lime, iron ore, and coals, and return with the iron manufactured into articles for home use and for exportation; while in a third, they transfer the raw cotton received from abroad, and return with manufactured cotton goods ready to supply every market in the World; and this with so little labour, that in one case, falling within the knowledge of the writer, a load of twenty-one tons in a boat of six tons, was drawn by a man and a young girl his daughter, at the rate of 1.9 mile per hour through the usual passage; the horse, which commonly did the work at a somewhat greater speed, being unable from accident to perform his usual duty.

As far as regards the mere force of traction, indeed, no means of conveyance for heavy goods can ever come in competition with Canals at a slow pace; but as Manufactures and Commerce increase, time becomes more valuable; speed is essential to every transaction; the mere charge of conveyance is of less consequence than the time of transfer, and hence the idea of Railways, which, indeed, seem in some few instances to have preceded the Canal; but they were constructed of wood, and were of course very imperfect.

(291.) The first wooden Railway seems to have been employed at Newcastle, in 1680, for transporting coals from the pits to the river Tyne, upon which duty, even at that time, there were employed from four hundred to five hundred carts; hence it became of course an object of manifest importance to reduce the great expense thereby incurred in the keeping up of horses, drivers, and roads; and the plan of wooden rails was the best, and, indeed, the only effectual method which could at that time have been devised for the purpose; for which also the situation was in other respects favourable, presenting in most cases an easy descent towards the river. These Railways were then very generally introduced, and continued for a long period in use in this part of the Kingdom. Slips of ground of the requisite breadth for the Railway were marked out between the coal pits and the river, and were either leased by the coal owners or purchased of the different proprietors whose ground the proposed line of road intersected in its course. To obtain the most easy and regular descent, this line was varied in its direction to meet the inequalities of the ground; or, where these inequalities were inconsiderable, it was carried straight forward, and the regular slope made by embankments and cutting. The ground being then smoothed and levelled, as for an ordinary road, large logs of wood, termed *sleepers* cut in lengths equal to the breadth of the road, were laid across it, and firmly bedded into it at short distances, to sustain and hold fast the rails or slips of wood on

Wooden
Railways.

Manufac-
tures.

which the waggon wheels were intended to run. These rails were made of beech, and were laid end to end, so as to form two continued lines of rails or wooden ridges, running parallel to each other along each side of the road, crossing the large logs at each of their extremities, on which they rested as on so many foundations; and were also nailed, or otherwise secured, to keep each piece in its proper place. The waggons were of the usual construction, but of a large size, so as to contain several tons of coals, and set upon low wheels, the smoothness of the way rendering wheels of the ordinary size unnecessary. On these rails a single horse could readily draw three tons of coal from the pits to the river. Where any steep declivity occurred on the road, this was termed a *run*, or an inclined plane; and on it the descent of the waggons was retarded, and regulated by a species of brake, or crooked lever, termed a *convoy*, attached to the waggon, and managed by the driver. The banks of the Tyne, near Newcastle, are remarkably steep on each side; but instead of forming inclined planes on them, the Railway was here continued on a wooden stage, raised to the same height as the top bank of the river, and carried forward until it came perpendicularly over the river side, where a wooden platform, termed a *staith*, was erected for the convenience of delivering the coals: the waggons being emptied into a trough or spout, down which the coals descended either directly into the ships, or into the store below.

Iron Rail-
ways.

(292.) *Of iron rails.*—Such was the construction of the original rail, in which is evidently perceived all the parts and members of the Railway, as it is formed at the present day; viz. the regular formed road, the rails, the sleepers, the low waggons, and the inclined plane. Their only defect consisted in the soft and decaying nature of the wood, the wear and tear of which caused so much expense for repairs as greatly limited their application; so that it was only the shortness of the distance, and the great extent of the traffic, which rendered their application at all beneficial. It was not till about the year 1738 that they were attempted in the collieries of Whitehaven; and it does not appear that they were adopted in any other part of the Kingdom. The use of iron, therefore, in the place of wood, was an essential improvement in the construction of Railways, and caused, indeed, a complete change in this, as it has done in every other branch of practical Mechanics into which it has been introduced. Flat bars of iron were at first fastened on the top of the wooden rails; but after various unsuccessful attempts, the rails themselves were at last wholly composed of iron, cast in short bars, united at their extremities, and resting on sleepers, or square blocks of stone, disposed at short distances along each side of the road; and this construction having been once fairly reduced to practice, was not only adopted universally in the place of wood, but soon led to new and more extensive applications. Iron Railways were quickly introduced into all the coal and mining districts of the Kingdom. They were employed on Canals, in place of locks, to raise the barges on an inclined plane from a lower to a higher level; in some instances they were adopted in preference to the Canal itself; and on the whole, forming an important auxiliary to inland navigation, pushing the channels of trade and intercourse into districts otherwise inaccessible, and even into the interior of the mines; and to so great an extent is this now carried, that, according to the Report of M. Dupin, the celebrated English voyager, the under-ground Railways alone in

Newcastle, and its immediate vicinity, exceed in length one hundred and fifty miles.

(293.) *Locomotive engines.*—Railways were thus carried to a great extent, but the transfer of the loads was made by the assistance of horses; one of these animals on a well-constructed iron rail would do more work than six horses on a common road, or, if necessary, instead of making him draw more, his speed might be increased: still, however, we were dependent on the horse, and the only use made of the Railway, till within a very few years, was the transfer of goods, or of various materials from one place to another, and great speed was neither attempted nor thought desirable. A very few years, however, has introduced an extraordinary change. Railways and locomotive engines are seldom now separated in imagination. With the horse we were limited in speed, however light his load he could not move with more than a certain velocity; but the locomotive engine is not thus circumscribed. Journeys have now been actually performed at a rate of motion far exceeding any thing that could have been contemplated some years ago; thirty-five miles per hour have been effected, twenty and twenty-five miles is the common pace, and to what further extent a practice, only yet in its infancy, may arrive, it is impossible to foresee.

Another step is still in progress. Hitherto, whether horse or locomotive engine has been employed, a Railway has been thought essential for the performance, and consequently this means of transfer could be procured only in particular lines of road, where there was sufficient traffic to answer the charge of a first great outlay; this drawback on general convenience has led to an endeavour to substitute locomotive carriages on common roads, or on roads rather exceeding in their state of perfection the common road, but without rails. Some journeys have been made with more or less success, but upon the whole, with so much as has led to the formation of a Company for establishing this mode of travelling, and there seems every probability that a few years will cover our roads with carriages of this description. Of course the power necessary to be employed in this case will be much greater than on a Railway; but the very general range which such carriages may take is so great, that it must be the wish of every one to see these well-intended efforts directed to a successful termination.

Having thus taken a general sketch of the progress of inland communications in Great Britain, we shall now enter a little more into detail, by examining the actual force of traction in the different modes of conveyance according to the results of the best experiments, the construction of different kinds of Railways, and a description of those locomotive carriages which have hitherto been most approved, either for Railway or for common roads.

Comparisons of the Force of Traction on Common Roads, Canals, and Railways.

(294.) *Common roads.*—There is necessarily great uncertainty in deductions formed from experiments made for the purpose of determining the force of traction on common roads; but the following, reported by Mr. Telford to the Society of Civil Engineers, made on different slopes, are amongst the best we can select, although there are discrepancies in these which are not easily to be explained.

Machinery
Locomotive
engines on
Railways.

On common
roads.

Force of
traction on
common
roads.

Manufactures.

Results of Experiments made with a Stage Coach weighing Eighteen Hundred Weight at different Slopes on the same Road.

Inclination.	Rate of travelling.	Force required.	Expense of drawing one ton per mile in a waggon at $2\frac{1}{2}$ miles per hour.
	Miles.	Pounds.	Pence.
1 in 20	6	268	22.83
1 in 26	6	213	
1 in 30	6	165	18.55
1 in 40	6	160	16.79
1 in 600	6	111	12.66
horizontal.		?	12.36
1 in 20	8	296	(Expense of drawing one ton per mile in a four-horse stage, at 10 miles per hour.)
1 in 26	8	219	
1 in 30	8	196	
1 in 40	8	166	
1 in 600	8	120	
1 in 20	10	318	50.47
1 in 26	10	225	
1 in 30	10	200	44.15
1 in 40	10	172	41.25
1 in 600	10	128	33.59
horizontal.	10	?	32.93

There are some anomalies in these results. First, it appears that a much greater force is necessary to move ten miles an hour than six, which is at variance with theory; for the force of resistance being balanced in both cases, there ought not be any difference in the force of traction, unless the resistance of the air should operate to this amount. In the next place, the forces at different slopes are not consistent; a change of slope from 1 in 20 to 1 in 30 seems to make a difference of 103 pounds, while the difference between 1 in 30 and 1 in 40, makes only a difference of 5 pounds. The traction on the level road is not given, but deducing it from the slope of 1 in 600, it would appear to be about 107 pounds, which is more than a twentieth of the load. It is, however, we believe, generally considered to be on a good turnpike road about one-thirtieth; it is so stated in Leslie's *Nat. Phil.*

The following results are also given on Mr. Telford's authority:—

1. On well made pavement, the draught (of each horse) in a waggon weighing about 21 hundred weight is thirty-three pounds.

2. On a broken stone surface or old flint road, sixty-five.

3. On a broken stone surface upon a bottom of concrete, formed of Parker's cement and gravel, forty-six.

4. On a broken stone road upon a rough pavement foundation, forty-six.

(295.) *Resistance on a Canal.*—On a road, the resistance is the same at all speeds, but in a Canal this is by no means the case. The common law of the resistance of fluids makes the resistance increase as the square of the velocity, but this does not hold good in Canals. From many experiments made by the writer on the Grand Junction and on the Birmingham Canals, there is no doubt the resistance varies very nearly as the cube of the velocity. This may, and probably does in part proceed from the water being confined by the sides of the Canal; moreover, the water always rises in front of the bow of the vessel, while a corresponding vacuity occurs at the stern, and this inequality is greater as the velocity is greater, whereas the theory supposes that every particle of water, as soon as it is struck, escapes and offers no further impediment; but from whatever source it arises, there can be no doubt that the resistance to a body in motion in a Canal varies very nearly as the cube of the velocity.

The manner in which the experiments above referred to, and of which the results are given below, were made, was by passing a rope over a pulley fixed to the regular towing post in the barge, which carried a basket containing different weights. This rope, which was smaller than the towing rope, was attached to the latter, which was taken on shore for hauling along the boat or barge, either by men or horse as stated below. After the motion had commenced and acquired the requisite uniformity, the amount of weight in the basket was adjusted by either adding or taking away some till the basket just sustained itself between the deck and pulley; and this weight, including that of the basket, &c., was considered the force of traction. Marks were previously made along the bank, at a chain's length distance from each other; a person was also present with a stop-watch, and when the motion had become uniform and the basket properly suspended, a sign was given to look out for the next mark; as the boat passed this, the time was noted, and again at the end of the distance, which varied in different experiments from thirty, forty, or more chains: by this means the velocity of the barge was very accurately determined. The estimated weight of the barge and the exact amount of the load were carefully registered, and the results of the experiments were as stated below, with some others made precisely in a similar way in the river Mersey, and one or two other places at which the writer was not present.

Machinery.

Resistance on Canals.

Experiments.

Manufactures.

TABLE showing the Resistance experienced with Canal Barges moving with different Velocities.

Machinery.

Description of the navigation.	Dimensions of barge.	Depth of the barge.	Usual velocity in miles.	Extent of the experiment.	Time of the experiment.	Velocity during the experiment in miles per hour.	Resistance.	Load in the vessel.	Load and vessel or whole effect.	Ratio of resistance to the load.	Ratio of resistance to whole effect.	Number of horses.	Worked by men.	Remarks.
	Feet.	Ft. In.		Chains.	Min.		lbs.	Tons.	Tons.					
48 ft. wide, 6 deep	62 $\frac{3}{4}$ long	1 8	..	..	..	4.9300	343	1.20	43 $\frac{1}{2}$	$\frac{1}{3}$	..	3	..	
	13 $\frac{3}{4}$ wide	2 0	5 $\frac{1}{4}$	79	12							2	..	
River Mersey	64 $\frac{1}{2}$ long	4 1	2 $\frac{1}{2}$	165	48	2.5757	242	40.0	92.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	2	..	
	14 $\frac{1}{2}$ broad													
ditto	ditto	2 0	3 $\frac{1}{2}$	265	56	3.5378	140	Empty	52.00	..	$\frac{1}{8}\frac{1}{8}$	2	..	Little wind, stream in favour.
ditto	64 $\frac{1}{2}$ long	2 0	3 $\frac{1}{2}$	265	33	3.7575	140	Empty	52.00	..	$\frac{1}{8}\frac{1}{8}$	1	..	Weight sometimes 98 pounds.
	14 $\frac{1}{2}$ broad													This is not quite correct.
Canal, 48 ft. wide, 6 deep	70 $\frac{1}{2}$ long	3 1 $\frac{1}{4}$	2 $\frac{1}{2}$	58.36	20 $\frac{1}{2}$	2.1625	100	23.00	31.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	6	..	
	7 broad													
ditto	64 $\frac{1}{2}$ long	4 1	2 $\frac{1}{2}$	19	30 $\frac{1}{2}$	5.7000	950	42.00	94.00	$\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	5	..	Not perfect.
	14 $\frac{1}{2}$ broad													
ditto	ditto	2 0	..	93.18	15	4.6591	900	Empty	52.00	..	..	..	men	
Canal, 30 ft. wide, 6 deep	69 long	2 5	..	36.8	6	4.6000	168	10.00	14.50	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
	3 $\frac{1}{2}$ broad													
ditto	ditto	2 5	..	30.27	4 $\frac{3}{4}$	4.6900	170	10.00	14.50	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	2 5	..	30.27	6' 15"	3.6300	77	10.50	15.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	2 5	..	30.27	7' 40"	2.9600	50	10.50	15.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	2 5	..	30.27	7' 40"	2.9600	50	10.50	15.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	68 long	1 8	..	39.27	15' 30"	1.9000	50	21.00	30.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	..	Worked by a man and girl.
	7 broad	2 7	..	39.27	10'	2.9450	66	10.75	19.75	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	..	With wind.
ditto	ditto	ditto	..	39.27	10' 30"	2.8050	91	10.75	19.75	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	Against wind.
ditto	ditto	ditto	..	39.27	10 $\frac{3}{4}$ '	2.7300	98	20.75	29.75	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	ditto	..	39.27	9'	3.2700	175	20.75	29.75	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	ditto	..	39.27	10 $\frac{1}{2}$ '	2.8050	164	21.00	39.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	ditto	..	18.63	5' 2"	2.5800	172	21.00	39.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	ditto	..	30.30	9' 5"	2.5000	196	42.00	60.00	$\frac{1}{3}\frac{1}{8}$	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	ditto	..	10 miles	4h. 5m	2.4500	80	24.00	31.00	..	$\frac{1}{8}\frac{1}{8}$	1	ditto	
45 ft. w. 5 dp.	69 long	ditto	..	10 chains	4 7	3.6400	80	Empty	6 $\frac{1}{2}$	..	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	ditto	..	10 chains	4 35	3.2700	64	Empty	6 $\frac{1}{2}$	..	$\frac{1}{8}\frac{1}{8}$	..	ditto	
ditto	ditto	ditto	..	10 chains	3 52	3.8700	308	21 $\frac{1}{2}$	27.00	..	$\frac{1}{8}\frac{1}{8}$	1	..	
ditto	ditto	ditto	..	10 chains	6.8	2.44	77	21 $\frac{1}{2}$	27.00	..	$\frac{1}{8}\frac{1}{8}$	..	ditto	

Law of resistance.

(296.) In order to arrive at a law of resistance as depending on velocity, it will be best to select for comparison those made in the same Canal, or in Canals of the same breadth; because, as we have already stated, it is not improbable that the law is in some measure influenced by the degree of facility with which the water can escape, or the want of that facility, which is of course greatest in the narrow Canal.

To arrive at this law let V, v represent two different velocities, and F, f the corresponding forces of traction; then supposing F to vary as some power of V , let m denote the index of that power, so that

$$V^m : v^m :: F : f;$$

$$\text{then } f V^m = F v^m$$

$$m \log V + \log f = m \log v + \log F.$$

$$\text{Whence } m = \frac{\log F - \log f}{\log V - \log v}$$

Now making this calculation for the different cases, we find from the Ellesmere boats 2 and 3 $m = 3.08$
 Ditto 3 and 4 $m = 2.60$
 Ditto 4 and 5 $m = 2.73$
 Grand Junction $m = 3.00$

$$\frac{4}{11.41}$$

$$2.85$$

which is nearly as the cubes; and the same appears to be the general character of the results, whether on light or heavy barges. It is useless, therefore, in the face of such experiments, to say that theory requires the power to be as the square. We have already stated a probable cause of the discrepancy, and whether that be sufficient or not, the fact is still the same; and we must proceed in our comparison with the results given by experiment,

and which are such as to prove the entire inutility of attempting to bring Canals to compete with Railways so far as speed is concerned; although some attempts of this kind have lately been made, wherein it is maintained that notwithstanding this law may be true in moderate velocities, an entirely different law has place with great velocities; that with these the boat will rise up on the wave which we have mentioned as impeding its velocity, and skim along its surface with a diminished instead of an increased resistance.

We are much afraid, however, that the increased resistance attending at least all common velocities, will always be an impediment to rapid canal transfer; and that the proprietors of these works must be content to proceed at their usual pace of two or two and a half miles per hour, at which rate no other means of conveyance can ever come in competition with them in regard to economy, notwithstanding the first outlay for such works is necessarily very great.

(297.) *Resistance on a Railway.*—The following results are collected from different Works, and all are resting on the best authorities.

- Ratio.
1. Mr. Silvester states that in empty waggons 23 $\frac{1}{2}$ hundred weight, the weight of the waggon itself, is moved along by a force of 14 pounds $\frac{1}{18}$
 2. On the same authority it appears that 50 pounds will overcome the friction and resistance of a loaded waggon on the same rail, weighing together with its load 76.25 hundred weight $\frac{1}{17}$
 3. Mr. Wood states that 50 pounds will draw along a horizontal rail a loaded waggon of 80 hundred weight $\frac{1}{17}$

Resistance on Railways.

Manufac-
tures.

4. Mr. Greenshaw says that 10 pounds will overcome the friction of an empty waggon weighing 2576 pounds on a horizontal rail. $\frac{1}{257}$
5. And that 50 pounds will draw along a like plane a loaded waggon of 8512 pounds. $\frac{1}{170}$
6. In another experiment resting on the same authority, it appears that on a rail whose inclination is $\frac{1}{180}$, the waggon will just descend without acceleration. $\frac{1}{180}$
7. And that in common practice 14 pounds will draw 23 hundred weight. $\frac{1}{184}$
8. And again, that on a rail whose inclination was $\frac{1}{9}$ of an inch to a yard, or $\frac{1}{32}$, the power necessary to draw down the loaded waggon of 8512 pounds, is equal to the drawing up the empty waggon of 2576 pounds; this gives. $\frac{1}{170}$
9. Mr. Jessop states that the best horizontal rail gives. $\frac{1}{200}$
10. But common practice not more than. $\frac{1}{150}$
11. Mr. Palmer reports that on an inclined plane at $\frac{1}{90}$, an empty waggon of 3666 pounds required a force of 5 pounds to prevent its descending. $\frac{1}{67}$
2. And that on an inclined rail of $\frac{1}{30}$, the same waggon required 108 pounds to prevent its descent. $\frac{1}{74}$

See the Works of the several authors above quoted on railways.

These experiments all tend to one result, which is important, viz. that the resistance increases faster than the weight; or that the greater the load the greater is the proportional power of traction: this is supposed to arise from the heavier loads bending in a slight degree the rail as it passes over it, whereby the effect is always equivalent to ascending a slightly inclined plane.

The usual Railway waggons are made to run on low wheels; if others of greater diameter were employed, there is no doubt both friction and resistance would be proportionally reduced.

(298.) From these results, and those before given on Canals, it is clear, that although with low velocities the force of traction is much less on Canals than on Railways, yet with a little increased velocity, the two become equal; after which the advantages are altogether in favour of the latter. It appears from the preceding Canal experiments, taking one on which the velocity is exactly $2\frac{1}{2}$ miles per hour, and its force of traction $\frac{1}{689}$ of the whole load; let it be required to find the velocity when the resistance shall be $\frac{1}{180}$, that is equal to the resistance on a good Railway; here

$$\frac{1}{689} : 2\frac{1}{2}^3 :: \frac{1}{180} : v^3,$$

or

$$v = \sqrt[3]{\frac{689}{180} \times 2\frac{1}{2}} = 3.91.$$

At a velocity, therefore, of about four miles per hour, the Canal and Railway give equal resistances; but at double that velocity, that is, at eight miles per hour, the advantages are eight to one in favour of the Railway. Supposing, as we have all along done, that the rail is perfectly horizontal, and abstracting from the resistance of the air, which is not considerable till the velocity becomes more than is here stated.

(299.) *Inclined rail.*—When a rail is inclined, and the carriage is either ascending or descending, the nature of the resistance is modified in two ways; first, gravity

Ratio.

has now its influence, and either tends to accelerate or retard the motion, according to the direction in which the carriage is moving, accelerating it in its descent, and retarding it in its ascent; and this effect, from the known laws of bodies on inclined planes, varies as the sine of the plane's inclination. Hence if the whole weight of the carriage and load be W , this effect will be expressed by $\pm W \sin a$; a being the inclination of the plane. Again, the pressure on the plane varies as the cosine of the angle; hence the friction and resistance being proportional, if $\frac{W}{m}$ denotes the friction on a hori-

zontal plane, $\frac{W}{m} \cos a$ will be the same on a plane whose angle of inclination is a . Whence again the whole resistance, abstracting still from that of the air, is expressed by

$$\text{Resist.} = \frac{W}{m} \cos a \pm W \sin a;$$

the upper sign having place when the carriage is ascending, and the lower when it is descending: therefore, in the latter case, when $\cos a = m \sin a$, the carriage will be in equilibrio on the plane; when $\cos a$ is greater than $m \sin a$, some force equal to the difference is necessary to sustain the carriage; but when $\cos a$ is less than $m \sin a$, the carriage will descend by the effect of gravity, unless some counteracting force be applied to check its motion.

In short rails, which are loaded only one way, the inclined plane presents great advantages, supposing the load, as very commonly happens, is to descend; for in this case the slope of the rail, or the proportion between the weight of the empty and loaded carriage may be so adjusted to each other, that the acceleration of the descending load shall just balance the retardation of the ascending waggon, or just so far exceed it as to produce the requisite degree of velocity in both.

Suppose, for example, the weight of the loaded waggon to be W , and that of the empty waggon w , then by the foregoing formula

$$W \sin a - \frac{w}{m} \cos a = \text{force of descending load};$$

$$w \sin a + \frac{w}{m} \cos a = \begin{cases} \text{retarding force of ascend-} \\ \text{ing empty waggon.} \end{cases}$$

Whence, when both are equal,

$$(m \sin a - \cos a) W = (m \sin a + \cos a) w;$$

therefore

$$\frac{W}{w} = \frac{m \sin a + \cos a}{m \sin a - \cos a};$$

from which expression the ratio of W to w is readily determined when the angle is given.

When the load is given, and the weight of the waggon required, then calling

$$\frac{W}{w} = r, \sin a = x, \cos a = y,$$

$$\frac{m x + y}{m x - y} = r,$$

$$m x + y = m r x + r y,$$

$$(r + 1) y = (m r - m) x;$$

or
whence

$$\frac{x}{y} = \frac{r + 1}{m(r - 1)} = \frac{\sin a}{\cos a};$$

and the ratio of the sine to cosine being thus determined, the angle itself will be readily obtained.

Machinery.

Resistance
on Canals
and Rail-
ways com-
pared.

Inclined
Railway.

Manufac-
tures.

Such questions as the above, however, only occur in particular cases; the great question of the economy of Railways, for general communication, is by supposing that the rails can be made horizontal, or so nearly so, that the accelerating force of gravity shall not exceed the resistance arising from friction and the usual retarding forces.

Action of
locomotive
engines on
railways.

(300.) In estimating the effect of locomotive engines on a Railway, it will be found that the force required is the same as if the centre of the wheel were fixed, and the resistance to the motion acted at the circumference of the wheel.

Pl. xxi.
Fig. 8.

Let C D, fig. 8, pl. xxi. represent the axles of the fore and hind wheels of a locomotive engine, which rest on a rail at the points A and B; and let a force act from some point of the carriage by the rod G F, upon the crank C F, which turns with the wheel C A round the axle C. The rod exerts a certain action on the crank at F, and an equal reaction on the carriage at G. If F G meet C A and D B, in H and E, the action on the wheel C A may be supposed to take place at H, and the reaction upon the carriage at E. Join C E, and draw H K parallel to C E, and let the equal action and reaction in the line G F or E H be represented by E H and H E.

The force E H is equivalent to K H, C H, of which the latter is supported and destroyed at A; the former is effective on the wheel C A.

The force H E is equivalent to K E, C E, of which the former diminishes the pressure at B, the latter draws C towards E.

Therefore the wheel C A is acted upon by two forces, K H, C E; which tend to turn it about A. Also the resistance which the carriage experiences to its motion in the direction C D may be considered as a force acting at C, perpendicular to C A. Let R be this force, and let A N M be perpendicular to C E, H K. Then the forces and the resistance must balance each other, and by the property of the lever, if S be the force K H, or C E,

$$R \times CA + S \times AN = S \times AM;$$

or $R \times CA = S \times MN.$

Let C O be drawn perpendicular from C upon E H, and H I upon C E; and let P be the pressure exerted by the rod G F; we then have

$$P : S :: EH : EC :: HI : CO :: MN : CO;$$

therefore

$$P \times CO = S \times MN;$$

and

$$R \times CA = P \times CO.$$

Hence the effect is the same as if C and the force P acted by means of the rod G F and crank C F to produce motion in the wheel, in opposition to a force R acting at the circumference.

In order that the engine may be urged in the direction C D, the force which acts by means of the rod G F must be a pushing force, while the line G F falls below C, and a pulling force when this line falls above C. If G be connected with the piston of a steam engine, these two parts of the motion must correspond to the up and down stroke, or the backwards and forwards stroke.—Whewell, *Mechanics' Appendix*.

Application
of steam
power on
rail roads.

(301.) *Application of steam power to Railway carriages.*—The first idea of moving Railway carriages by steam power was that of employing stationary engines, by means

of which and ropes the requisite motion was produced; a method which was successfully practised in one or two early cases, and was even recommended by two highly respectable Civil Engineers, as the best that could be adopted for the Liverpool and Manchester Railway; but this opinion was fortunately overruled by that of the Company's Engineer and the majority of the proprietors.

The inconvenience which first led to the idea of stationary engines was what is called the *skidding* of the wheels. When a carriage is drawn by a horse, or any other first mover, by traces proceeding from the line of the axle, or above or below it, the road itself furnishes a fixed point from which the power proceeds, and towards which the carriage is urged, and at which it must arrive, supposing the power sufficient, if even the wheels were fixed on their axle; but being free, or nearly so at this place, and the circumference meeting with a resistance at the surface of the road, the wheel must necessarily revolve on its axle, and the carriage itself advance forward; all that is requisite for this effect being, that the resistance on the road shall be greater than that at the axle. But if the motive power is in the carriage itself, and its effort be to turn the wheel on its axle, then, unless the resistance at the circumference of the wheel exceeds a certain amount, the wheel will be turned round, but the carriage will remain stationary. This inconvenience was anticipated rather than experienced in the early attempts to work by locomotive engines; the power employed, for want of proper arrangement, frequently turning the wheels back without any, or at least without a proportionate advance of the vehicle. To avoid this imaginary evil the rail was made like a rack, and the wheels with corresponding teeth, and, of course, when the power was applied the carriage was urged forward; but this was found to possess many disadvantages—the motion was rough, and the wear and tear enormous. We believe, however, this practice continued in one or two places for some time.

Another method, intended to avoid the evil above mentioned and to apply steam power to common roads, was, to employ propelling bars from the carriage, the motion of which was made as nearly as possible to imitate the hind legs of a horse, by which a fixed point was found at every stroke of the bar, and the carriage was forced forward. This was exceedingly ingenious; but a serious accident having happened in one of its early experiments, by which several lives were lost, it was laid aside, and the practice discontinued, at least on a large scale. But we have seen a model acting on similar principles with four propellers, which performed its duty remarkably well. It being, however, now well understood that the resistance, not only on a road but on a rail may be rendered amply sufficient to propel the carriages, all the above methods are laid aside, and no thought is now entertained of producing the motion in any other way than that of the direct application of the power to the wheel itself.

(302.) As in most other inventions of great public utility, Treve-thick's loco-motive. different persons have come forward to claim the honour of the first idea, and some idle controversy has been going forward on the subject in a few of our Journals. These, however, are scarcely worth attention. To suggest an idea or to form a model, is certainly one step, but to carry the idea into practice is a greater. At all events it will be sufficient for our purpose to state, that two years after Mr. Trevethick's patent for a high pressure engine, described in (Art. 205.) the inventor con-

Machinery.

To common
roads.

Manufactures.

constructed a Machine of the same kind for the purpose of moving carriages or locomotive engines, which in 1804 was successfully applied on the Rail road at Merthyr Tydvil in South Wales. In this engine the cylinder was placed horizontally, the piston working in the direction of the line of road; the extremity of this rod, by means of a connecting rod, worked cranks placed on the axletree, on which were two cogged wheels fixed on the axle of the hind wheels of the carriage, and by which this axle, together with its wheel fixed to it, were made to revolve, and so long as the friction of the wheel and the rail exceeded the resistance to be overcome, the carriage with its train was urged forward. To this engine was an appendage, no longer thought necessary for road carriages, namely, a fly wheel, which was attached to the axle of the propelling wheel. The fore wheels are described as being capable of turning like the fore wheels of a carriage, so as to enable a director to guide the vehicle. On its first trial it drew after it as many carriages as contained ten tons of iron a distance of nine miles, which stage it performed without any fresh supply of water, and travelled at the rate of five miles per hour.

From this time, now thirty years past, locomotive carriages have become a popular and interesting object; great ingenuity has been displayed, great obstacles and strong prejudices have been overcome, and a work, the Liverpool and Manchester Railway, has been completed, which is not only the admiration of this Country but of the World.

Blinkin-

sop's patent.

In 1811, Mr. Blinkinsop took out his patent for the rack rail and toothed wheels above mentioned, but which failed, for the reasons already stated.

Chapman's patent.

In the following year, 1812, Mr. Chapman took out his patent for working a locomotive engine by a chain extending along the middle of the line of Rail road, from one end to the other. This chain was passed once round a grooved wheel under the centre of the carriage, so that when this grooved wheel was turned by the engine, the chain being incapable of slipping upon it, the carriage was necessarily urged forward. In order to prevent the strain acting on the whole length of the chain, its links were made to fall upon upright forks placed at certain intervals, which between those intervals sustained the tension of the chain produced by the engine. Friction rollers were used to press the chain into the grooves of the wheel, so as to prevent it from slipping. The friction of the chain, however, was found so great that the experiment may be said to have totally failed.

Brunton's patent for road locomotive engines.

In the following year, 1813, Mr. Brunton took out his patent for the propelling rods; but being laid aside by its ingenious inventor, after the accident to which we have alluded, it will not be necessary for us to do more than make this record of the attempt.

Experiment on the adhesion of wheels and rails.

The evils which all these inventions were intended to obviate, were in the following year demonstrated to be merely imaginary. The experiment by which this important point was established was made on the Wylam Rail road; where it was shown that when the road was level, and the rails clean, the friction between the wheels and rail was sufficient, in all kinds of weather, to propel considerable loads. It was first ascertained how much weight the wheels of common carriages would overcome without slipping round on the rail, and having thus the proportion that this bore to the weight, it was found that the weight of the engine would produce sufficient

adhesion or friction to drag after it on the Rail road the requisite number of waggons.

Machinery.

This cleared away a great difficulty, and from that time daily improvements have been made in the construction of carriages for this purpose. It does not appear, however, that the impression was quite removed on this point, as it was thought necessary at first to make use of the friction of all four wheels. Mr. Stephenson's carriage for the Killingsworth Rail road, had its hind and fore wheels connected by an endless chain, the cogged wheels hitherto employed were abandoned, and the rotation produced by an immediate connection of a crank upon them with the piston rods. This engine had two cylinders, one over each pair of wheels, the cranks being so arranged that when the weak point of one crank was in action, the other crank was in its best position; and this relation of the two cranks was preserved by the endless chain above mentioned which passed over both. The boiler was cylindrical, and the chimney proceeding from the end of the carriage was turned upwards in front. In a subsequent engine by the same engineer, the endless chain was abandoned, it having been found that considerable power was lost, and unnecessary friction incurred by this arrangement. It is obvious, indeed, that unless all four wheels are precisely of the same size, the chain will constantly have to drag along the wheel of smallest diameter; and although every possible pains should be taken, and the diameter of all the wheels made perfectly equal at first, which is scarcely possible, yet an unequal degree of wearing would soon destroy the equality, and produce the evils to which we have referred. It would be useless to pass in review the various form of locomotive carriages which have appeared in a few years on different Railways, principally intended for the carriage of goods and heavy luggage; we shall proceed, therefore, at once to a description of the Manchester and Liverpool Railway, which embraces in itself every valuable information on this subject.

Rapid improvement in the application of locomotives.

(303.) *Description of Liverpool and Manchester Railway.*—The extraordinary increase of the Manufactures at Manchester, and the corresponding traffic between that place and Liverpool, rendered necessary a proportional increase in the facility of communication. There were already two lines of Canals between these places, but they were inadequate to the demands of Trade and Commerce, as appears from the following declaration, signed by upwards of one hundred and fifty of the most respectable merchants of Liverpool.

Liverpool and Manchester Railway.

"We, the undersigned merchants and brokers, resident in the Port of Liverpool, do hereby declare, that we have for a long time past experienced great difficulty in obtaining vessels to convey goods from this place to Manchester, and that the delay is highly prejudicial to the Trading and Manufacturing interests at large; that we consider the present establishments for the transport of goods quite inadequate, and that a new line of conveyance has become absolutely necessary to conduct the increasing Trade of the Country with speed, certainty, and economy."

It was accordingly determined to establish a Company for the formation of a double Railway from Liverpool to Manchester; and on the 29th October, 1824, the first prospectus of the Company was issued. The advantages promised by this prospectus, and in an amended one afterwards substituted, were briefly these: A saving of time and of money in the transmission of

Manufac-
tures.

the one thousand tons or more conveyed between the two towns daily; the increase of Commerce and Manufactures by increased facility of intercourse; an improved channel for the conveyance of the Manufactures and agricultural produce of Ireland to the populous towns of Lancaster and York; the carriage of farming produce to the large towns, and the return of lime, manure, &c., to the farmers; speedier conveyance for travellers; and the carriage of coals to Liverpool and Manchester from the valuable mines in the vicinity of St. Helen's, the coals having been heretofore brought to Liverpool principally by Canal, a distance of thirty miles, whilst by the Rail road the distance would be less than half, and the price materially reduced. The quantity of coals consumed annually in Liverpool and Manchester was estimated at one million of tons, and it was calculated that the saving in the price of this necessary article of domestic consumption alone would amount to at least two shillings per ton, or £100,000 annually in the consumption of the two towns.

On the 28th of February, 1825, a petition was brought into Parliament for leave to bring in a Bill, which having gone through several stages, was lost, or rather withdrawn on the 1st of June following; the Canal proprietors having used every possible effort to bring about the result. The question was, however, again brought forward in February of the following year, and was then carried in both Houses; in the Commons by a majority of forty-seven, and in the House of Lords without a division.

Before we enter upon a description of the operations which were commenced in June of the same year, 1826, it will be well to inform the reader of the nature of the difficulties which were to be surmounted. The turnpike road between Liverpool and Manchester measured about thirty-four miles; but by taking as nearly a straight line as possible, the line of the proposed Railway was only thirty-one miles. The Docks at Liverpool are sixty-six feet below the level of Manchester; but the land rises at Edgehill, in the immediate neighbourhood of the former, a hundred and sixty-nine feet above the Docks. This ground is a hundred and three feet above the level of Manchester, and the surface of the land between the two extremes is alternating above and below the level of Edgehill, the highest point being two hundred and five feet above the Docks, and the lowest only twenty-six feet. It was necessary that this line should be rendered as nearly level as possible, for any great ascents or descents would altogether have destroyed the advantages otherwise obtainable by such works. The land also rising so abruptly behind Liverpool, a sudden ascent was necessary, and to avoid interfering with the town itself, it was determined to cut a tunnel under it. This tunnel, which was in some places carried through solid rock, is 1970 yards, and rises one in forty, ascends a hundred and twenty-three feet, at which point it is of course forty-six feet below the top of Edgehill, and twenty-five feet above the artificial level of the rail at Manchester. If this could have been thrown into one general slope, it would have been so inconsiderable as to have been tantamount to a level plane. But this could not be effected, and certain inclinations, both ascending and descending, occur in the course of the line, as in the following dimensions taken from the section:

Inclined plane from Wapping to Edgehill, forming the tunnel 1970 yards, a rise of $\frac{1}{48}$

Level by cutting.	1000 yards.		
Edgehill to Wavertree to Huy-			
ton.	5 $\frac{1}{2}$ miles,	fall	$\frac{1}{1000}$
Wiston inclined plane.	1 $\frac{1}{2}$ do.	rise	$\frac{1}{90}$
Rainhill level	1 $\frac{1}{2}$ do.		
Sutton inclined plane	1 $\frac{1}{2}$ do.	fall	$\frac{1}{90}$
Parr Moss to Sankey canal and			
viaduct	2 $\frac{1}{2}$ do.	fall	$\frac{1}{200}$
Sankey viaduct to Bury Lane. .	6 $\frac{1}{2}$ do.	fall	$\frac{1}{800}$
Chat Moss	5 $\frac{1}{2}$ do.	rise	$\frac{1}{1200}$
Baston, Eccles, Munches. . . .	4 $\frac{1}{2}$ do.	level.	

With these ascents and descents, which, of course, were only admitted to save expense, the labour was still very great. Amongst other operations requiring construction were sixty-three bridges; the cuttings amounted to nearly 720,000,000 cubic yards, and the embankments to 277,000 cubic yards, which, together with tunnelling and other works, presented a charge which none but British merchants could have ventured to have undertaken, and perhaps only British engineers could have executed.

(304.) *Commencement of the work.*—In the following year the work was begun by the draining of Chat Moss. This commenced in June. In September of the same year the first shaft of the Liverpool tunnel was opened; and during the whole of 1827, the formation of it under Liverpool was carried forward with spirit and perseverance. Night and day the excavation proceeded, and many difficulties in the execution of the work had to be overcome. In some places the substance excavated was a soft blue slate, with abundance of water; in other places a wet sand presented itself, which required no slight labour and contrivance for its support, till the masonry which was to form the roof was erected. In passing under Crown Street, near the Botanic Garden, for want of sufficient props, the superincumbent mass, consisting of loose moist earth and sand, fell in from the surface, a depth of thirty feet. On some occasions the miners refused to work, and it not unfrequently required the personal superintendence and encouragement of the engineer to keep them at their posts. But while some portions of the tunnel were excavated under circumstances of no little difficulty and danger, other portions were hewn through a fine red sandstone, clean, dry, and substantial, which required neither props nor artificial arching, the natural rock forming the roof of the excavation. The tunnel was constructed in seven or eight separate lengths communicating with the surface by upright shafts, through which the substance excavated was conveyed away. On the 9th of June, 1828, it was reported to the Directors that the last joining between the several lengths was effected, and that all very serious difficulties in the execution of this branch of the undertaking were surmounted.

In 1828, was principally effected the piling for the foundations of the piers of the great viaduct over the Sankey valley; a business of much labour and cost, but indispensable for the security of the superstructure. About two hundred piles, varying from twenty to thirty feet in length, were driven hard into the foundation site of each of the ten piers. The heavy ram employed to impart the finishing strokes, hoisted up with double purchase and a snail's pace to the summit of the piling-engine, and then falling down like a thunderbolt on the head of the devoted timber, driving it, perhaps, a single half-inch into the stratum below, is well calculated

Machinery.

Commence-
ment of the
work in
1827.

Continua-
tion of the
work in
1828.

Manufactures.

Machinery

In 1829.

Preparatory experiments.

to put to the test the virtue of patience, while it illustrates the old adage of "slow and sure."

During 1828, was completed the Company's bridge over the turnpike road and the old mill-dam at Newton, and the operations at Chat Moss were carried on without intermission, embanking at each end, and draining, levelling, &c., in the centre portions.

In the Spring of 1829, the Directors being desirous of proceeding with increased despatch in the execution of the work, instructed the engineer to order the contractors at the principal cuttings throughout the line, to employ two sets of labourers, and to work by night as well as day. The operations accordingly proceeded still more rapidly than heretofore, though it must be allowed at considerably increased expense; and had it not been for the extraordinary wet Summer and Autumn, the earth-work for a complete line of communication between Liverpool and Manchester, might have been accomplished by the end of 1829, or the beginning of 1830, and the Railway laid down for operations within a few months from that period. As it was, very considerable delay was occasioned by the heavy and long-continued rains, besides no trifling expense to the Company in pumping the water from the deep cuttings, which were too apt to assume the appearance of a Canal rather than a Railway.

The principal structure, completed in 1829, was the Company's bridge to carry the Liverpool and Warrington turnpike road over the Railway at Rainhill.

Before the close of 1829, one roadway along the whole extent of Chat Moss was completed; and on the 1st May, 1830, the Rocket steam engine, with a carriage and company, passed over it. That the practicability of carrying the Railway over this Moss should have been questioned, is not to be wondered at, considering that it was in some places from thirty to thirty-five feet deep, and so soft and pulpy that an iron rod would sink through it by its own gravity. The portion of the Moss which presented the most difficulty, was about half a mile on the Eastern border, where an embankment of about twenty feet had to be formed above the natural level. The weight of this embankment resting on a semi-fluid base pressed down the original surface; many thousand cubic yards gradually and silently disappeared before the line of road made any approach to the proposed level. By degrees, however, the whole mass beneath and on each side of this embankment became consolidated by the superincumbent and lateral pressure, and perseverance finally completed the work.

In September, 1829, was commenced the Company's bridge over the Irwell; the last great structure on the line of Railway from Liverpool to Manchester.

(305.) At this time it had not been determined by what means the carriages were to be transported along the rail; whether by horses, by stationary steam engines, or by locomotives.

The great theatre of practical experience on Railways, was previously the Stockton and Darlington line, and the Railways in the vicinity of Newcastle-on-Tyne. All the modes heretofore in use of propelling carriages on Railways, namely, by horses, by locomotives, and by fixed engines, had been there exemplified, but facts were wanted to lead to a correct decision, and personal observation seemed necessary in order to arrive at a satisfactory result. The Directors accordingly appointed two of their own Body, accompanied by Mr. Booth, their Treasurer, to proceed to Darlington and the neighbourhood of

Newcastle, to obtain, on the spot, the requisite information, and to report the same to the Board, with their opinion on the subject. This journey of inspection took place in the beginning of October, 1828, and the deputation returned with a fund of information, but of so mixed, and, in some respects, of so contradictory a nature, that the great question as to the comparative merits of locomotive and fixed engines was as far from being settled as ever. One step only was gained; the deputation were perfectly convinced that for the immense traffic to be anticipated on the Liverpool and Manchester line, horses were out of the question. In these circumstances the Directors resolved on calling in the assistance of two professional engineers, to enable them to determine which it would be best to adopt, fixed or locomotive engines; and the gentlemen selected for this purpose were Messrs. Walker and Rastrick.

On the 9th of March, 1830, two separate Reports from these engineers were laid before the Directors. The merits and demerits of each system were therein very fully and fairly stated; and in the opinions of Messrs. Walker and Rastrick, they were pretty equally balanced. The cost of an establishment of fixed engines between Liverpool and Manchester, they were of opinion, would be something greater than of locomotives to do the same work; but the annual charge, including interest on capital, they computed, would be less on a system of fixed engines than with locomotives. The cost of moving a ton of goods thirty miles, that is, from Liverpool to Manchester, by fixed engines, they estimated at 6.40d. and by locomotives at 8.36d. supposing in each case a profitable traffic both ways. But with a system of locomotives, the cost of the first establishment need only be proportioned to the demands of the trade, while with stationary engines an outlay for a complete establishment would be required in the first instance. And it was further to be considered, that there appeared more ground for expecting improvements in the construction and working of locomotives than of stationary engines. On the whole, however, and looking especially at the computed annual charge of working the road on the two systems on a large scale, Messrs. Walker and Rastrick were of opinion that fixed engines were preferable, and accordingly recommended their adoption to the Directors.

Mr. Stephenson, the Company's engineer, had always been in favour of locomotive engines; and notwithstanding this decision of Messrs. Walker and Rastrick he was still decidedly of opinion, that they would be found to furnish the most economical and most convenient moving power that could be employed. Moreover, the inclination of a majority of the Directors continued in favour of locomotives, provided they could be so constructed as to consume their own smoke, (agreeably to the provisions of the Railway Act,) and of an adequate power, and of a less weight than the engines then in use, which were generally from eight to ten tons, which was supposed to produce injury to the Rail road, and to incur a proportional expense in keeping it in repair. The Directors determined, therefore, to obtain, if possible, locomotive engines of improved construction that should be of lighter weight. In order to effect this, a premium was offered of £500 for the most approved carriage to be constructed and submitted to trial early in October of 1829.

This premium, as might be expected, acted as a great stimulus to exertion, not merely for obtaining the

Manufactures.

pecuniary, but the honorary reward, which would attend success in such a trial. The day ultimately appointed was the 6th of October. The umpires were Messrs. Rastrick and Wood, Civil engineers, with J. Kennedy, Esq. of Manchester. The portion of the Railway set apart for the trial was on the Manchester side of Rainhill bridge, about nine miles from Liverpool, where the Railway runs about two or three miles on a dead level.

Early in the day a great number of persons were collected from all parts to witness this extraordinary exhibition; many from great distances, principally engineers, scientific men, and amateurs in Science, most of them well qualified to judge not only of the merits of the different engines, but also of the advantages of the great national question with which the experiments were connected. The number of steam locomotives were four, as follows:

Pl. xxi.
Fig. 1, 2, 6,
7.

1. Messrs. Braithwaite and Ericson, of London. This engine was named the "Novelty," and weighed empty two tons fifteen hundred weight, represented in pl. xxi. fig. 1.
2. Mr. Ackworth, of Darlington, the "Sans Pareil," weighing four tons eight and a half hundred weight; fig. 2.
3. Mr. Robert Stephenson, the "Rocket," weighing four tons three hundred weight; fig. 6.
4. Mr. Brandreth, of Edinburgh, the "Perseverance," weighing two tons seventeen hundred weight. The figure of this engine is not given. Fig. 7 is a representation of the present general and most approved form of locomotive on the Manchester Railway.

(306.) The Rocket first appeared in running trim, but not for the grand trial, and drew a weight besides itself of twelve tons nine hundred weight, at a rate exceeding ten miles per hour, and when relieved of its load, its speed was eighteen miles per hour.

On the following day, the Novelty showed some preliminary practice; the engine without a load is said to have started into a pace of twenty-eight miles per hour, and with its load at twenty and three-quarter miles per hour; but the distance is not stated. At this time it does not appear that the conditions were well known, by which the merits of the engines were to be determined. These were, however, now propagated, viz. that the engines were not to exceed in weight six tons; that each was to draw three times its own weight at first starting, and to go a distance of seventy miles at not less than ten miles per hour.

Report of
the experi-
ments.

The grand trial now commenced. The Novelty commenced, but unfortunately bursting one of its pipes, failed of accomplishing the journey. The Sans Pareil met with a similar accident and was withdrawn, after it had performed twenty-two and a half miles in one hour and thirty-seven minutes, and was bidding fair to carry off the prize; its greatest speed was fifteen miles per hour. The Perseverance seems to have had no chance of success. The above two, and the Rocket, were therefore the only engines which may be said to have contended, or to have had any chance of obtaining the prize, which was finally awarded to the Rocket, this engine having run the whole distance twice, the first time in two hours, fourteen minutes, eight seconds, the second in two hours, six minutes, forty-nine seconds. The speed averaging in one case eleven and a half miles per hour, and in the other thirteen four-

tenths. Its greatest speed was twenty-nine miles per hour, and its least eleven and a half miles. Machinery.

In a case like that above detailed, every exertion would be made; the engines would be brought to the ground in the best working trim, and we may, perhaps, expect some little exaggeration in unauthorized reports of their performance, which were very numerous; but sufficient was done to show that, notwithstanding much had been effected, more might be anticipated, and this expectation has been fully borne out by the practice of the last three years. In these trials the engines were only called upon to drag three times their own weight, and the best speed of the winning engine, the Rocket, was twelve and a half miles per hour, while the engines at present, on their common duty, drag ten or twelve times their own weight, and generally preserve a medium rate of twenty miles an hour, and the train for passengers twenty-four miles per hour.

From this date the question between locomotive and fixed engines was considered to be practically settled. The fitness of locomotives for the purposes of travelling at almost any speed that could be desired was strikingly exemplified. But there still remained one point to be settled, namely, the *kind of power* to be employed in ascending the inclined planes of Whiston and Sutton. These planes are each a mile and a half long, with an inclination of three-eighths of an inch to a yard, being a rise of one in ninety-six. Stationary engines on the summit, with ropes passing over sheaves or pulleys along the whole ascent, are the means resorted to at the inclined plane in the Liverpool Tunnel; also on the Darlington inclined planes, and at the Collieries in the North. It was quite evident, however, that such a plan of operations in the centre of the Manchester and Liverpool line, with the interruption to be expected from a change of the moving power, not to mention the danger always to be apprehended from a system of ropes and pulleys, was to be avoided if possible. It became an object, therefore, of great interest to ascertain the power of the new locomotives on the planes in question. During the trials at Rainhill, in October, 1830, the Rocket frequently ascended the Whiston inclined plane with a carriage holding from twenty to thirty passengers, at a speed of from fifteen to eighteen miles per hour; and the ease and regularity with which this was effected produced a general impression, that even up inclined planes the locomotive engine would be the power employed. Indeed, the feeling at the moment was very prevalent, that it was immaterial whether the engine travelled up an inclined plane or on a level; but subsequent experiments have fully established, what it would have been only reasonable to assume *a priori*, that the power of an engine diminishes in proportion to the degree in which the plane is inclined, till it reaches a point, when, adhesion terminating, the wheels turn round without advancing; and, therefore, without assistance of some sort up such inclined planes as those of Whiston and Sutton, an engine must go either at a less speed or draw a less weight. For example: the Comet locomotive, a new engine on the same plan as the Rocket, ascended the Whiston inclined plane with about twenty-six tons behind it, with a speed diminishing from the rate of between sixteen and eighteen miles at the commencement, to about three or four miles per hour before it reached the top; this is the unavoidable consequence of the inclination, which necessarily throws, in this case, where the slope is one in ninety-six, a ninety-sixth part

Experiments on
the inclined
planes.

Manufactures.
Abstract of disbursements.

of the load upon the engine, an amount far exceeding the whole friction on a level plane.

(307.) *Abstract of expenses.*—The following general abstract of the expenditure of the Railway, to the 31st of May, 1830, showing the cost of the different branches of the undertaking, may be interesting to the reader.

	£.	s.	d.
Advertising account	332	1	4
Brickmaking account	9,724	4	4
Bridge account	99,065	11	9

The number of bridges is 63, of which one is of 9, a second of 4, and a third and fourth of 2 arches. The rest are of one arch each.

Charge for direction	1,911	0	0
Charge for fencing	10,202	16	5
Cart establishment	461	6	3
Chat Moss account	27,719	11	10

The embankments included under this head consist of about 277,000 cubic yards of raw moss earth, in the formation of which about 677,000 cubic yards of raw moss earth have been used; the difference of measurement being occasioned by the squeezing out of the superabundant water and consequent consolidation of the moss. The expenditure on this part of the line has been less than the average expenditure.

Cutting and embankments	199,763	8	0
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Under this head is comprised the earth-work on the whole line, exclusive of the Chat Moss district. The cutting somewhat exceeds the embankments; the surplus is principally deposited along the border of the Great Kenyon cutting. The excavations consist of about 722,000 cubic yards of rock and shale, and about 2,006,000 cubic yards of marl, earth, and sand. This aggregate moss has been removed to various distances, from a few furlongs to between three or four miles; and no inconsiderable portion of it has been hoisted up by Machinery, from a depth of from 30 to 60 feet, to be deposited on the surface above, either to remain in permanent spoil banks, or to be afterwards carried to the next embankment.

Carrying department, comprising account expended in land and building for stations and depots, warehouses, offices, &c. at the Liverpool end	£35,538	0	0
Expended at the Manchester station	6,159	0	0
Side tunnel	2,485	0	0
Gas light account, including cost of pipes, gasometer, &c.	1,046	0	0
Engines, coaches, machines, &c.	10,991	11	4

Formation of the road	56,219	11	4
	20,568	15	5

By this is understood what is termed ballasting the road, that is, depositing a layer of broken rock and sand about two feet thick; viz. one foot below the blocks and one foot distributed between them, serving to keep them firm in their places. Spiking down the iron chains to the blocks or sleepers, fastening the rails to the chains with iron keys, and adjusting the Railway to the exact width, and curve, and level, come under this head of expenditure.

Rail account	69,912	0	2
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This expenditure comprises the following items:

Rails for a double way from Liverpool to Manchester, with additional lines of communication, and additional side

Carried up...	495,880	6	10
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Brought up...	£.	s.	d.	Machinery.
	495,880	6	10	

lines at the different depots, being about 35 miles of double way = 3847 tons, at prices averaging something less than £12. 10s. per ton	£48,000	0		
Cast iron chains, 1428 tons, at an average of £10. 10s.	15,000	0		
Spikes and keys to fasten the chains to the blocks and the rails to the chains	3,830	0		
Oak plugs for blocks	615	0		
Sundry freights, cartages, &c. .	467	0		
Interest account (balance)	3,629	16	7	
Land account	95,305	8	8	
Office establishment	4,929	8	5	
Parliamentary and law expenditure	28,465	6	11	
Stone blocks and sleepers	20,520	14	5	
Out of the 31 miles about 18 are laid with stone blocks, and 13 with wooden sleepers, oak or larch; the latter being laid principally across the embankment and across the two districts of moss.				
Surveying account	19,829	8	7	
Travelling account	1,423	1	5	
Tunnel account	34,791	4	9	
Tunnel compensation account	9,997	5	7	
Waggons used in the progress of the work .	22,185	5	7	
Sundry payments for timber, iron, petty disbursements, &c.	2,227	17	3	
	£739,185	5	0	

This account, it will be observed, reaches only to May 31, 1830, at which time the work was not complete; and it appears by a Report of the Directors that in December 1831, the capital expended on the whole work amounted (including engines, coaches, waggons, &c.) to £992,054. 3s. 6d.

(308.) Taking, now, a view of the work as completed, the entrance in the Company's yard at Wapping, Liverpool, is by an open cutting twenty-two feet deep and forty-six feet wide, affording space for four lines of Railway; between these lines are pillars supporting the floors of the Company's warehouses, to which there are hatchways or trap doors, allowing the waggons placed below to be readily loaded and unloaded. Here the inclined plane and tunnel commence: the breadth is twenty-two feet, side walls five feet high, with a semicircular arch of eleven feet radius, making the height sixteen feet, and the length, as before stated, one thousand nine hundred and seventy yards, rising, on an inclination of one in forty-eight, one hundred and twenty-three feet. This tunnel, through its whole length, is furnished with gas-lights, suspended from the centre of the arched roof, at a distance of twenty-five yards; and the sides and roof are whitewashed, the better to reflect the light. At the upper end, the tunnel terminates in a large open area about forty-six feet below the summit of Edgehill, cut out of the solid rock, and surmounted on every side by walls and battlements. From this area, another shorter tunnel branches quite distinct from the larger one, which communicates with the upper part of Liverpool. Its dimensions are two hundred and ninety yards long, five wide, and twelve feet high. It terminates in the Company's premises in Crown Street, which is the principal station for the Railway coaches. Above this area are erected two lofty chimneys belonging to the stationary steam engines at this place for bringing the carriages up the inclined plane; they are each one hundred feet high, and are built to represent columns with handsome capitals.

From this station, proceeding Eastward, the road

General view of the work as completed.

Manufac-
tures.

passes through a Moorish archway; this connects the two engine-houses, and forms the grand entrance of the Liverpool stations. The road in this part curves slightly, but is perfectly level for one thousand yards; it then falls, as before stated, for more than five miles, on a slope of four feet to a mile, or $\frac{1}{100}$. About half a mile to the North of the village Wavertree a passage is cut through a steep eminence called Olive Mount; this cutting is more than two miles in extent, in solid rock, some parts of which are seventy feet below the surface, and only sufficiently wide for the two trains of carriages to pass each other. It winds gently round to the South-East, and the view is bounded by the perpendicular rock on either side. Four hundred and eighty thousand cubic yards of stone have been removed in forming this excavation, a good deal of which has been employed in building the bridges, walls, &c., in this part of the line; the bridges here being principally to form communications between the roads and farms cut through by the Railway.

Emerging from the Olive Mount cutting, the road is thence artificially raised by the great Roby embankment which is nearly three miles in length, varying in height from fifteen to forty-five feet, and in breadth at the base from sixty to one hundred and thirty-five feet. This is formed of the materials dug out from the various excavations. The quantity employed was five hundred and fifty thousand cubic yards. After passing the Roby embankment, the Railway crosses, by means of a bridge, over the Huyton turnpike road; and proceeds in a slightly curved direction to Whiston, between seven and eight miles from the station at Liverpool. Here the Rail road continues for a mile and a half in a straight line, having in its length an inclination of one in ninety-six; at the top of this inclined plane the road runs nearly two miles on an exact level, produced by the excavation of two hundred and twenty thousand cubic yards. Over this part, called Rainhill level, the turnpike road between Liverpool and Manchester proceeds, crossing the line of Railway at an acute angle of 34° by means of a substantial stone bridge. At the other side of this two miles of level is the Sutton inclined plane, which is similar in extent and inclination to the Whiston plane descending from Rainhill in the opposite direction. A little distance thence is Parr Moss, over which the road is carried. This moss is twenty feet deep, and extends three-quarters of a mile in the line. The materials for the road which forms the Railway on this unsubstantial matter were obtained from the excavations of the Sutton inclined plane which produces one hundred and forty-four thousand cubic yards of clay and stone. The heavy deposit sank to the bottom, and now forms with the moss a firm embankment, in reality twenty-five feet high, though only four or five feet above the surface of the other parts of the moss. Not very far from this, and about half way between Liverpool and Manchester, is the valley of the Sankey, at the bottom of which the Canal flows. Over this valley, without interruption to its navigation, the Railway is carried along a magnificent viaduct, supported on nine arches; each arch is fifty feet span, and varies from sixty to seventy feet in height; these are built principally of brick with stone facings: the width of the Railway between the parapets is twenty-five feet. The piling for the foundation of the piers of this great viaduct was a business of much labour and cost, but indispensable for the security of the superstructure.

The approach to this structure is by an embankment attaining to the height of sixty feet. This is formed principally of clay dug out from the high lands on the borders of the valley. Not far from Sankey is Newton, near to which town the Railway crosses a narrow valley by a short but lofty embankment, and by a handsome bridge of four arches, each having forty feet span. The turnpike road from Newton to Warrington passes under one of these arches, and beneath another flows a small river. At Kenyon, a few miles beyond Newton, is an excavation of greater magnitude than any other on the line, eight hundred thousand cubic yards of clay and sand having been dug out of it. Near the end of this cutting, the Kenyon and Leigh Junction Railway joins the Liverpool and Manchester line by two branches, pointing to the two towns respectively. This Railway joins the Bolton and Leigh line, and thus forms the connecting link between Bolton, Liverpool, and Manchester. After the Kenyon excavation is the Brosely embankment, and a little beyond commences the Chat Moss. The difficulties overcome here have already been briefly described; and now, by the ingenuity and perseverance of man, trains of carriages of many tons weight are constantly passing and repassing over a bog, which originally would not allow of a person walking over it except in the driest weather. About a mile from the extremity of the moss, the Railway crosses the Duke of Bridgewater's canal, by a neat stone bridge of two arches. Some little distance beyond is the village of Eccles, four miles from Manchester. Through this extent is an excavation from which two hundred and ninety-five thousand cubic yards of earth have been dug out. At Manchester the Railway crosses the river Irwell by a very handsome stone bridge, of two arches of sixty-five feet span, thirty feet from the water; and then over a series of twenty-two arches, and a bridge, to the Company's station in Water Street. The whole line of road is a distance of thirty-one miles from the Liverpool station. The Railway is there on a level with the second story of the Company's warehouses, and by six large doors, or gateways, the waggons may be rolled into them and conveniently discharged or loaded under cover.

We have thus brought up the particulars of this great national undertaking to the end of May, 1830. In the following month preparations began to be made for the opening, which was expected to take place in the latter end of the Summer. On the 14th of June, in that year, an experiment was made as a measure to the anticipated opening, well calculated to exhibit the peculiar character of Railway conveyance, and to put to the test the capabilities of the locomotive engine, both on a level and up inclined planes. On this occasion, the Directors, in two carriages, proceeded on a journey of inspection from Liverpool to Manchester and back. The Arrow, another of Mr. Stephenson's engines, was the proving power. The gross weight drawn was about thirty-three tons, consisting as follows:

	Tons.
Stone in seven waggons	20
Weight of waggons	7
Engine tender and six persons	3
Two carriages and twenty persons ..	3
	33

With this load she travelled from the engine-house, Liverpool, to Old Field Lane Bridge, Salford, Manchester, the distance being about twenty-nine miles, in

Experi-
ments pre-
paratory to
opening the
works.

Manufac-
tures.

two hours and twenty-five minutes, including two stoppages to take in water. Up the Whiston inclined plane she was assisted by the Dart, an engine of similar construction and power; and the first quarter of a mile of the ascent was accomplished at a speed of seventeen miles per hour before the summit was gained, the mile and a half being accomplished in twelve minutes; the average speed being, therefore, seven and a half miles per hour. At the top of the ascent the Dart was unyoked, and the Arrow proceeded with her cargo along the straight and level plane at Rainhill at the rate of sixteen miles per hour. On the return from Manchester the engine-tender and the two carriages, with passengers, constituted the whole load drawn. The first nine and a quarter miles from Old Field Lane Bridge to Glazebrook Bridge, including the Chat Moss district, were accomplished at a speed averaging from nineteen to twenty miles per hour. The whole distance was accomplished in one hour and forty-six minutes, including stoppages, the speed generally varying from eighteen to twenty-five miles and upwards per hour, and the engine not working to her full power a great portion of the way. The speed up the Sutton inclined plane (without any assistant engine) averaged more than fifteen miles per hour. The day was wet, and the rails in some places were very dirty; the whole performance, therefore, took place under circumstances by no means favourable, but the result was highly satisfactory.

Opening
the Rail-
way.

(309.) From this time, preparations were going forward, and every thing arranged for the opening, which was ordered to take place on the 15th of September. This was not a case of ordinary occurrence, and it was the wish of all concerned that this important ceremonial should be worthy of the occasion; accordingly, every necessary preparation was made to give effect to the scene, and every pains taken to avoid such accidents as might be expected from the concourse of people which would doubtless be present. All loose stones and rubbish which lay at the mouths of the tunnels, and on different parts, were removed; the rails were well swept, and strong paling was erected on each side of the deep cuttings for several miles. A strong Body of police and some military were in attendance, to preserve order, and to keep the Railway clear. The persons to whom places were assigned in the procession were requested to assemble at the Company's Station in Crown Street, at half-past nine in the morning. Each engine and its train of carriages had distinguishing flags; the colours of the admission cards corresponded with those of the flags, and every card bore the number of the seat which was allotted to its possessor. The number of locomotive engines employed on the occasion was eight, named as follows:—the Northumbrian, the Phoenix, the North Star, the Rocket, the Dart, the Comet, the Arrow, the Meteor. The whole of these engines had been built by Messrs. Stephenson and Co., of Newcastle; the Rocket being the same that bore off the prize in the preceding year: the rest were constructed on a similar plan, varying only in dimensions, and in some indifferent matters of arrangement. It was expected that three engines also, constructed by Messrs. Braithwaite and Ericsson, on their patent principle, would have been in readiness, namely, the far-famed Novelty, and two new engines which these engineers had contracted to build for the Railway Company, not exceeding five tons weight, and capable of drawing forty tons gross, at the rate of fifteen miles an hour; the consumption of coke

not to exceed half a pound weight per ton per mile. But these engines not having arrived from London early enough to be subjected to a preliminary trial, the Directors thought it would not be prudent to allow them to make part of a procession which it was of the utmost consequence should be exposed to as few risks of failure as possible. The whole of Messrs. Stephenson and Co.'s engines had, we believe, been repeatedly tried, and with success, several weeks before.

Machinery.

The Northumbrian was appointed to take the lead of the procession, drawing a splendid carriage, appropriated to the reception of the Duke of Wellington, Sir Robert Peel, and about thirty other distinguished individuals, who honoured the ceremony with their presence. Each of the other locomotives drew four carriages, containing between eighty and ninety persons; so that the total number of individuals accommodated with seats in the procession must have been about six hundred.

At twenty minutes to eleven o'clock the procession commenced its progress towards Manchester, the Northumbrian taking exclusively one of the two lines of rail, and the rest of the engines the other. The brilliancy of the *cortège*, the novelty of the sight, considerations of the almost boundless advantages of the stupendous power about to be put in operation, gave to the spectacle an interest unparalleled. On every side the tumultuous voice of praise was heard, and countless thousands waved their hats to cheer on the sons of enterprise in this their crowning effort. The engines proceeded at a moderate speed towards Wavertree Lane, when increased power having been added, they went forward with great swiftness, and thousands fell back, whom all the previous efforts of a formidable police could not move from the road. Numerous booths and vehicles lined the various roads, and were densely crowded. After passing Wavertree Lane, the procession entered the deep ravine at Olive Mount, and the eye of the passenger could scarcely find time to rest on the multitudes that lined the roads, or admire the various bridges thrown across this great monument of human labour. Shortly afterwards Rainhill bridge was neared, and the inclined plane of Sutton began to be ascended at a more slackened rate. The summit was soon gained, and twenty-four miles an hour became the maximum of the speed. About noon the procession passed over the Sankey viaduct. The scene at this part was particularly striking. The fields below were occupied by thousands, who cheered as the procession passed over the stupendous edifice; carriages filled the narrow lanes, and vessels in the water had been detained, in order that their crews might gaze up at the gorgeous pageant passing far above their mast-heads. Shortly after it passed the Borough of Newton, and reached Parkside, seventeen miles from Liverpool. Here the engines stopped to take in a supply of water and fuel, and many of the company having alighted in the interval, were walking about congratulating each other on the truly delightful treat they were enjoying, all hearts bounding with joyous excitement, and every tongue eloquent in the praise of the gigantic work now completed, and the advantages and pleasures it afforded, when the scene was in a moment changed from joy to mourning. Every thing was again nearly ready to proceed, and some of the line of carriages which had been left a little behind were already in motion moving forwards with great speed. Mr. Huskisson was standing near the Duke

Manufac-
tures.

of Wellington's carriage inside the line, and seeing the other carriages approaching with fearful rapidity, he lost his presence of mind, was thrown down by them on their approach, and the engine passed over his leg and thigh, which were so dreadfully injured that, after lingering a few hours, he expired. This accident, of course, threw a general gloom over the proceedings; the journey, however, was continued, although considerably delayed; and the engines having reached Manchester, returned again to Liverpool in the evening.

Commence-
ment of
regular
traffic.

(310.) On the following morning, the regular business of the Railway commenced. The Northumbrian left Liverpool with one hundred and thirty passengers, and arrived at Manchester in one hour and fifty minutes; in the evening it returned with one hundred and twenty passengers and three tons of luggage in an hour and forty-eight minutes: this was the first journey for hire. The next day six carriages commenced running regularly between the two towns, at three separate hours of the day; but which from the number of passengers were necessarily soon increased. The whole number of passengers between the 17th of September and December 31, 1830, was 70,000: between the 1st of January and 1st of July, 1831, 188,726; and in the next six months the numbers were increased to 256,321: a like astonishing increase took place in the carriage of merchandise and luggage, as will be seen by the following abstract of the first year's traffic, receipts, and disbursements; viz. from January 1 to December 31, 1831.

1st of January to 1st of July, 1831.

Abstract of
receipts and
disburse-
ments for
the first
year.

	Tons.
Merchandise carried between Liverpool and Manchester	35,865
Between Liverpool and the Bolton Junction	6,827
	42,692

Coals from Collieries near Liverpool 2,889

Passengers booked at Company's Office 188,726, exclusive of passengers taken up on the road.

The gross receipts of this traffic were as follows:

	£.	s.	d.
Passengers	43,600	7	5
Merchandise	21,875	0	1
Coals	218	6	2
	£65,693	13	8

amounting to 4s. 7½d. per passenger booked, and 10s. 3d. per ton for merchandise.

The disbursements upon the same traffic were as follows:

	£.	s.	d.
Coaching department for passengers ..	19,099	16	5
Merchandise, &c.	16,279	7	5
	Total ..	35,379	3 10
Profit	30,314	9	10
	£65,693	13	8

1st July to 31st December, 1831.

	Tons.
Merchandise between Liverpool and Manchester .	52,224
Traffic on the road	2,347
	54,571

Between Liverpool and the Bolton Junction 10,917
Coal from the adjacent Collieries 8,396

Passengers booked, exclusive of those taken up on the road, 256,321

Receipts.

	£.	s.	d.
Coach department	58,348	10	0
Merchandise	30,764	17	8
Coal	695	14	4
	£89,809	2	0

Expenses.

	£.	s.	d.
Passengers' department ...	25,930	1	1
Merchandise	21,841	4	10
Coal department	505	16	3
Bolton Junction	748	16	3
	49,025	18	5
Net profit	40,783	3	7
	£89,809	2	0

Machinery

The profits from the opening to December 31, 1831, were as follows:

	£.	s.	d.
From September 16 to December 31, 1830...	14,432	19	5
From January 1 to June 30, 1831.....	30,314	9	10
From July 1 to December 31, 1831	40,783	3	7
Total ..	£85,530	12	10

In 1832 there was a decrease in the number of passengers, but a further increase in luggage, and which now appears to average 1300 tons daily.

(311.) With respect to the capabilities of the engines, these appear to show a corresponding improvement. In the trials made with the experimental carriages they were required to draw only three times their own weight; they now draw ten, twelve, and even fifteen times their own weight. These carriages, also, were called upon to perform ten miles an hour; the common speed is now nearly twenty. On this head the following experiments made by Dr. Lardner are very satisfactory; since he was a disinterested man of great practical and theoretical Science, who had permission from the Directors to ascertain every fact, and examine into every circumstance stated in the following details of three following experiments.

First experiment.—On Saturday, the 5th of May, 1831, the engine called the Victory took 20 waggons of merchandise, weighing gross 92 tons, 19 hundred weight, 1 quarter, together with the tender containing fuel and water, of the weight of which I have no account, from Liverpool to Manchester, (30 miles,) in 1 hour, 34 minutes, 45 seconds. The train stopped to take in water half way for 10 minutes, not included in the above-mentioned time. On the inclined plane rising 1 in 96, and extending 1½ mile, the engine was assisted by another engine called the Samson, and the ascent was performed in 9 minutes. At starting, the fire-place was well filled with coke, and the coke supplied to the tender accurately weighed. On arriving at Manchester, the fire-place was again filled, and the coke remaining in the tender weighed. The consumption was found to amount to 929 pounds net weight, being at the rate of one-third of a pound per ton per mile.

Speed on the level was 18 miles an hour; on a fall of 4 feet in a mile, 21½ miles an hour; fall of 6 feet in a mile 25½ miles an hour; on the rise over Chat Moss 8 feet in a mile, 17½ miles an hour; on level ground sheltered from the wind, 20 miles an hour. The wind was moderate, but direct ahead. The working wheels slipped three times on Chat Moss, and the train was retarded from 2 to 3 minutes.

The engine on this occasion was not examined

Details of
perform-
ance by Dr
Lardner.

First experi-
ment.

Manufactures.

Second experiment.

Third experiment.

Remarks.

before or after the journey, but was presumed to be in good working order.

Second experiment.—On Tuesday the 8th of May, the same engine performed the same journey, with 20 waggons, weighing gross 90 tons, 7 hundred weight, 2 quarters, exclusive of the unascertained weight of the tender. The time of the journey was 1 hour 41 minutes.

The consumption of coke 1040 pounds net weight, estimated as before. Rate of speed:—

Level	17½ miles per hour.
Fall of 4 feet in a mile	22 ditto
Fall of 6 ditto	22½ ditto
Rise of 8 ditto	15 ditto

On this occasion there was a high wind ahead on the quarter, and the connecting rod worked hot, owing to having been keyed too tight. On arriving at Manchester, the cylinders were ordered to be opened, and it was found that the pistons were so loose, that the steam blew through the cylinders with great violence. By this cause, therefore, the Machine was robbed of a part of its power during the journey; and this circumstance may explain the slight decrease in speed, and increase in the consumption of fuel, with a lighter load in this journey compared with that performed on the 5th of May.

The Victory weighs 8 tons 2 hundred weight, of which 5 tons 4 hundred weight rest on the drawing wheels. The cylinders are 11 inches diameter, and 16 inches stroke, and the diameter of the drawing wheels is 5 feet.

Third experiment.—On the 29th of May, the engine called the Sampson (weighing 10 tons 2 hundred weight, with 14-inch cylinders, and 16-inch stroke, wheels 4 feet 6 inches diameter, both pairs being worked by the engine, steam 50 pounds pressure, 130 tubes) was attached to 50 waggons laden with merchandise, net weight about 150 tons, gross weight, including waggons, tender, &c. 223 tons 6 hundred weight. The engine with this load travelled from Liverpool to Manchester (30 miles) in 2 hours and 40 minutes, exclusive of delays upon the road for watering &c., being at the rate of nearly 12 miles an hour. The speed varies according to the inclinations of the road. Upon a level it was 12 miles an hour; upon a descent of 6 feet in a mile it was 16 miles an hour; upon a rise of 8 feet in a mile, it was about 9 miles an hour. The weather was calm, the rails very wet, but the wheels did not slip even in the slowest speed, except at starting, the rail being at that place soiled and greasy with the slime and dirt to which they are always exposed at the stations. The coke consumed in this journey, exclusive of what was raised in getting up the steam, was 1762 pounds, being at the rate of a quarter of a pound per ton per mile.

From the above experiments it appears, that a locomotive engine in good working order, with its full complement of load, is capable of transporting weights at an expense in fuel amounting to about four ounces of coke per ton per mile. The attendance required on the journey is that of an engine-man and a fire-boy; the former being paid 1s. 6d. for each trip of 30 miles, and the latter 1s. In practice, however, we are to consider, that it rarely happens that the full complement of load can be sent with the engines; and when lesser loads are transported, the *proportionate expense* must, for obvious reasons, be greater. During the previous Winter, the loads commonly transported by engines like the Victory, were about 35 tons, latterly they have been considerably increased; and at present, with the assist-

VOL. VII.

ance of another engine on the inclined plane, the ordinary load is, we are informed, about 100 tons gross.—*Machinery*
Lardner, *Lectures on the Steam Engine*.

Having thus given a concise sketch, first of the operations attending the construction and formation of the Railway, the expense attending that construction, and the successes which have attended the adoption of the locomotive engine, the result of the first year's revenue and disbursements, and the above well-authenticated account of three journeys, which are under the common order of working at present, we shall now proceed to give a description of engines, carriages, &c.

(312.) *Description of the engines.*—We have not hitherto interrupted the general detail of the Railway operations of the engines. by any particular description of the carriages; it will be proper, however, now to describe the nature of their construction. The Rocket is represented in plate xxi. fig. 6. It is supported on four wheels; the principal part of the weight being thrown on one pair which are worked by the engine by means of the crank shown in the figure. The boiler A consists of cylinders six feet long with flat ends. The chimney ascends from the end in front, and to the other is attached a square box B, the bottom of which is furnished with the grate on which the fuel is placed. This box is composed of two castings of iron, one contained within the other, having between them a space about 3 inches in breadth; the magnitude of the box being 3 feet in length, 2 feet in width, and 3 feet in depth. The casing which surrounds the box communicates with the lower part of the boiler by a pipe marked C; and the same casing at the top of the box communicates with the upper part of the boiler by another pipe marked D, where water is admitted into the boiler, therefore it flows freely through the pipe C into the casing which surrounds the furnace or fire-box, and fills this casing to the same level as that which it has in the boiler. When the engine is at work the boiler is kept about half filled with water; and, consequently, the casing surrounding the furnace is completely filled. The steam which is generated in the water contained in the casing, finds its exit through the pipe D, and escapes into the upper part of the boiler. A section of the engine, taken at right angles to its length, is represented at fig. 5. Through the lower part of the boiler pass a number of copper tubes of small size, which communicate at one end with the fire-box, and at the other with the chimney, and form a passage for the heated air from the furnace to the chimney, the ignited fuel spreads on the grate at the bottom of the fire-box, disperses its heat by radiation, and acts in this manner on the whole surface of the casing surrounding the fire-box; and thus raises the temperature of the thin shell of water contained in that casing. The chief part of the water in the casing being lower in its position than the water in the boiler, acquires a tendency to ascend when heated, and passes into the boiler; so that a constant circulation of the heated water is maintained, and the water in the boiler must necessarily be kept at nearly the same temperature as the water in the casing. The air which passes through the burning fuel, and which fills the fire-box, is carried by the draught through the tubes which extend through the lower part of the boiler, and as these tubes are surrounded on every side with the water contained in the boiler, this air transmits its heat through these tubes to the water, and finally issues into the chimney, and rises by the draught. The power of this furnace must

2 L

Manufac-
tures.

Pl. xxi.
Fig. 5.

Fig. 6.

Fig. 2.

Fig. 1, 3.

necessarily depend on the power of the draught in the chimney, and to increase this, and at the same time dispose of the waste steam after it has worked the piston, this steam is carried off by a pipe L, which passes from the cylinder to the chimney, and there escapes in a jet which is thrown upwards. By the velocity with which it issues from this jet, and by its great comparative levity, it produces a strong current upwards in the chimney, and thus gives force to the draught of the furnace. In fig. 5, the grate bars are represented at the bottom of the fire-box at F. There are two cylinders, one only of which appears in the elevation, fig. 6. The spokes which these cylinders work on as cranks, are placed at right angles on the wheels, which latter are fixed on one common axle which revolves with them. In this engine, the surface of water surrounding the fire-box exposed to the action of the radiant heat, amounted to twenty square feet, which received heat from a surface of six square feet of burning fuel on the bars. The surface exposed to the action of the heated air amounted to one hundred and eighteen square feet. The engine drew after it another carriage, containing fuel and water; the fuel used was coke, for the purpose of avoiding the production of smoke.

The next experimental engine, the Sans Pareil, is represented in fig. 2, and the horizontal section in fig. 4. The draught here is produced in the same manner as in the engine above described, but the boiler differs from the former very considerably. In this a recurved tube passes through the boiler. In the horizontal section, D represents the opening of the furnace at the end of the boiler by the side of the chimney. At A are shown the grated bars supporting the fuel, and a curved tube, passing through the boiler and terminating in the chimney, is seen at B, the direction of the draught being denoted by the arrow. C is a section of the chimney, the cylinders are placed as in the Rocket on each side the boiler, but vertically, each working the connected wheels on one side, and acting on spokes on the opposite sides, at right angles with each other. The space, in which the grate and flue are placed, diminishes in diameter as it approaches the chimney. At the mouth where the grate is placed, its diameter is two feet, and is gradually reduced to fifteen inches. The grate bars extend five feet into the tube. The surface of water exposed to the radiant heat of the fire, is sixteen square feet, and that exposed to the heated air and flame seventy-five square feet. The surface of the grate which sustained the fuel ten square feet.

The Novelty is represented in fig. 1, and a section of the generator and boiler in fig. 3; the corresponding parts in the two figures are marked by the same letters. A is the generator or receiver, containing the steam which works the engine; this communicates with a lower generator B, which extends in a horizontal direction the whole length of the carriage. Within the generator A is contained the furnace F, which communicates in a tube C, carried up through the generator, and terminated at top by sliding shutters which exclude the air, and which are only opened to supply fuel to the grate F. Below the grate the furnace is not open as usual to the atmosphere, but communicates by a tube E with bellows, which are worked by the engine, and which forces a constant stream of air, by the tube E, through the fuel on F, so as to keep that fuel in a high state of combustion. The heated air, contained in the furnace F, is driven on by the same force through the small

curved tube e, which circulates like a worm through the horizontal generator or receiver, tapering gradually till reduced to very small dimensions, when it finally issues into the chimney. The air, in passing along this tube, imparts its heat to the water, by which the tube is surrounded, and is brought to a considerably reduced temperature when discharged into the chimney. The cylinder, which is represented at K, works one pair of wheels by means of a bell crank, the other pair, when necessary, being connected with them. In this engine, the area, or the surface of burning fuel, is less than two square feet, the surface exposed to radiant heat nine and a half square feet, and the surface of water exposed to the heated air about thirty-three square feet.

Of these different boilers, that first described in the Rocket appears decidedly the best, although it has some imperfections, arising from the expansion of the tubes; it is, however, the one most preferred, and is the invention of Mr. Booth, the Treasurer of the Company, but the principle has been still further extended in the engines more recently constructed by Mr. Stephenson. Indeed, from the time of the first commencement to the present time, scarcely a month has passed without suggesting some changes in the detail; by which fuel is saved, the production of steam rendered more rapid, the wear of the engine diminished, and the strength of the different parts rendered more truly proportionate to the amount of strain, or the deteriorating action to which they are exposed. The consumption of fuel in the Rocket, to transfer a ton a mile, was 2.41 pounds of coke, and in the Sans Pareil, 2.47 pounds; in subsequent engines it was reduced to 1.42 to 1.25, and is now, as has been seen by Dr. Lardner's experiments, reduced to one-third, or even to one-fourth pound per ton per mile.

By the exposure of the cylinders in the Rocket, and engines of a similar form, to the atmosphere, a great waste of heat was incurred, and it was accordingly determined to remove them from the exterior of the boiler, and to place them within a casing immediately under the chimney; this chamber was necessarily kept warm by its proximity to the end of the boiler, but more by the current of heated air which constantly rushes into it from the tubes. This change also rendered another necessary, which fortunately likewise tended to improve the working of the engines. In the former engines the piston rods were connected with one of the spokes of the wheel as a crank, outside the carriage; this, however, was now impracticable; at least it was found more convenient to connect the piston rods of horizontal cylinders by cranks at right angles to each other, on the axles of the great wheels. By this means it was found that the working of the Machine was more equable, and productive of less strain than in the former arrangement. One inconvenience, however, followed, that the bent axle to form the crank was much more liable to accident; to prevent which, much greater thickness and weight are necessarily employed, and even with these some fractures have ensued.

In the more recent engines two safety valves are introduced, one of them locked up from the engine man. The tubes are smaller and more numerous than in the early engines, and the heat is more completely extracted from the air before it enters the chimney, and other modifications are being constantly introduced, preserving, however, at the same time, the general principle of the first construction, which may be thus enumerated.

Machinery

Manufactures.

Pl. xxi.
Fig. 7.

First, the great power of draught in the furnace, by projecting the waste steam into the chimney; second, the great abstraction of heat from the air, by its passage through the tubes, traversing the boiler; and third, which is however a new principle of working, keeping the cylinders warm by immersing them in the chamber under the chimney. These principles, pushed to a greater extent in almost every new engine, have greatly improved the locomotive engine, and there can be no doubt that much more will still be effected. In plate xxi. fig. 7, is represented one of the most approved railway engines. A is the cylindrical boiler, the lower half of which is traversed by small tubes, as already described; these are usually from eighty to one hundred in number, about one and a half inch in diameter; the boiler is seven feet long; the fire chamber is affixed to one end of it at F, and the other end is immediately under the chimney. The piston rods are supported in a horizontal position by guides, and connecting rods extend from them, under the engine, to two cranks placed on the axle of the large wheels. The effects of inequalities in the road are counteracted by springs, being below the axle of the great wheels, and above that of the less. The steam is supplied to the cylinder, and withdrawn by means of the common sliding valves, which are worked by an eccentric placed on the axle of the great wheels of the carriage. The motion is communicated from this eccentric to the valve by sliding rods. The stand is placed for the attendant at the end of the engine, next the fire-place F, and two levers, L, L, project from the end, which communicate with the valves by means of the rods, by which the engine is governed, to stop or reverse the motion. The wheels of these engines were at first constructed of wood with strong iron tires and flanges, but recently iron wheels have been introduced with hollow iron spokes. The hinder carriage is drawn by the engine as usual, containing fuel and water; and when the load is of a medium weight, the engines perform the journey from Liverpool to Manchester without a fresh supply of water; but when the load is heavy, a supply of water is taken in at the usual station in the middle of the journey.

Concluding remarks.

(313.) We may here bring to a conclusion our description of locomotive Railway engines, and after the several remarks interspersed in the different divisions of the subject, we have but few to make in this place. We have traced the engine through its successive grades, and have shown a general advance of it towards perfection. We have seen a reduction of fuel of more than one thousand per cent. with an increase of speed, if not in the same ratio, of a very considerable amount; and we cannot but still anticipate further ameliorations. At present the enormous wear and tear of the engine is the great drawback upon the many other advantages such works possess; and we cannot but hope that practice will lead to a great alteration in this respect. The speed, perhaps, hitherto aimed at is unnecessarily great; and if this were diminished, the power of the engine, and the intensity of the fire, need not be pushed to the same extent, which would, no doubt, contribute very largely towards a reduction of expenditure. In all future Railways, it ought also to be a great object to obtain as level a road as possible, even at a great expense in the first outlay. In the rail we have described, the greatest rise is one in ninety-six, but even this renders the power necessary to ascend it nearly three times as great as that which will draw the load along a horizontal plane. The

resistance on a good rail, we have seen, is about $\frac{1}{180}$ th of the load, whereas to ascend a plane of $\frac{1}{96}$, a ninety-sixth part of it has to be actually lifted, making the whole force required as above stated nearly three times what is requisite on the plane, and if such force cannot be employed, the load must either move slower or be helped up by an additional engine. There is great danger also, if the power is sufficient to take the load up the plane without assistance, that the friction on the rail will be inadequate to the action, and if it is sufficient for this, it is undoubtedly much too great, or more than is requisite, for the plane. All inclinations are, therefore, very injurious to Railway carriages, and ought, as above stated, to be as far as possible avoided, even at a great increase in the first expense. Another object, or one which, indeed, may be said to be involved in the former, is to keep the locomotive carriage as light as can be, with reference to the amount of resistance it has to overcome; for we have seen in the experiments on Railways, given in the early part of this Essay, that heavy loads cause a resistance much more than is proportionate to the weight, and which is accounted for by such condensed pressures deflecting the rail as they pass along, thereby always producing an effect similar to that of drawing a carriage up an inclined plane; this is a point, however, on which we will not insist, because it is one, no doubt, which has attracted the attention of the Directors of the Liverpool rail, and they have rather increased than diminished the weights of their engines, and the loads they have to draw, from the commencement to the present time. Of course the attendance on one large engine costs less than for two others, each of half the weight and power, and probably the first cost of the one is also less than that of the other two, which may, in some measure, balance the evil above mentioned. Practice, however, will settle all these points, and ultimately establish rules and principles of working, highly valuable to future directors of such works.

In writing the above account, we have availed ourselves of the labours of several authors, which it was not thought necessary to particularize as we proceeded. Besides the Parliamentary Report of the Committee on the Liverpool and Manchester Railway, and the Report of the Commissioners for the Holyhead roads, we have been much indebted to Mr. Booth's Report. To the Works on Railways by Tredgold, Wood, Gray, and Palmer, to Dr. Lardner's Lectures on the Steam Engine, and to various Periodical Journals, amongst which we ought to mention the *Mechanics' Magazine*, whose Editor throughout has directed his particular attention to the progress of the Work last described. The *Journal of Elemental Locomotion*, and Mr. Gordon's *Treatise on Locomotive Engines* have also been occasionally consulted, but the latter two more particularly for the following Section.

Application of Locomotive Engines to common Roads.

(314.) It remains for us to notice the progress which has been made in the application of locomotive engines on common turnpike roads. The employment of these engines on Railways may be said to be fully established, although the practice may not yet have arrived at perfection; but their application to common roads is certainly in its infancy, much still remaining to be effected, although a great deal has been done; indeed quite sufficient to prove that the object is practicable and attainable by

Machinery

Application of locomotives to common roads.

Manufac-
tures.

perseverance. Already journeys have been made to Bath, Southampton, Stratford on Avon, and to other places. Steam coaches have made the regular journeys between one town and another, like common Stages, for months in succession; but private interest and popular prejudices have too frequently interfered with the progress, and prevented the continuance. A Society is, however, now in progress of being formed, with one of our most distinguished engineers to direct its proceedings, whose object is the general establishment of these carriages, on several of the most frequented roads in the Kingdom, while Parliament has interfered to protect the ingenious speculator from the impositions to which they have been too often exposed by certain turnpike trusts.

The history of this practice is recent, and confined to a short period, and cannot be better given than in the precise words of the Report of a Committee of the House of Commons, appointed to inquire into, and report upon the proportion of tolls which ought to be imposed upon coaches and other vehicles propelled by steam or gas upon turnpike roads; and also, to inquire into, and to report upon, the rate of toll actually levied upon such coaches or other vehicles under any Acts of Parliament now in force; and who were instructed to inquire generally into the present state and future prospects of land carriage, by means of wheeled vehicles, propelled by steam or gas on common roads, and to report upon the probable utility which the Public may derive therefrom; and who were empowered to report the minutes of the evidence taken before them to the House. This Committee having examined the matters referred to them, agreed to the following Report.

Parlia-
mentary
Report on
the applica-
tion of loco-
motives to
common
roads.

(315.) "The Committee proceeded in the first instance to inquire how far the science of propelling carriages on common roads, by means of steam or mechanical power, had been carried into practical operation; and whether the result of the experiments already made had been sufficiently favourable to justify their recommending to the House that protection should be extended to this mode of conveyance, should the tolls imposed on steam carriages by local Acts of Parliament be found prohibitory or excessive.

"In the progress of their inquiry, they have extended their examination to the following points, on which the chief objections to this application of steam have been founded; viz. the insecurity of carriages so propelled, from the chance of explosion of the boiler, and the annoyance caused to travellers on public roads, by the peculiar noise of the Machinery, and by the escape of smoke and waste steam, which were supposed to be inseparable accompaniments.

"It being also in charge to the Committee, to report upon the proportion of tolls which should be imposed upon steam carriages, they have examined several proprietors of those already in use, as to the effect produced on the surface of roads by the action of the propelling wheels.

"As this was too important a branch of their inquiry, to rest entirely on the evidence of individuals, whose personal interest might have biassed their opinions, the Committee also examined several very scientific engineers, by whose observations on the causes of the ordinary wear of roads, they have been greatly assisted.

"The Committee were directed also to report on the probable utility which the Public may derive from the use of steam carriages. On this point they have examined a Member of the Committee, well known for his

intelligence and research on subjects connected with Machinery. the interests of Society, and they feel that they cannot fulfil this part of their instructions better than by merely referring the House to the evidence of Colonel Torrens.

"These inquiries have led the Committee to believe that the substitution of inanimate for animal power, in draught on common roads, is one of the most important improvements in the means of internal communication ever introduced. Its practicability they consider to have been fully established; its general adoption will take place more or less rapidly, in proportion as the attention of scientific men shall be drawn by public encouragement to further improvement.

"Many circumstances, however, must retard the general introduction of steam as a substitute for horse power on roads. One very formidable obstacle will arise from the prejudices which always beset a new invention, especially one which will at first appear detrimental to the interests of so many individuals. This difficulty can only be surmounted by a long course of successful, though probably unprofitable, experiments. The great expense of the engines must retard the progress of such experiments. The projectors will, for a long period, work with caution, fearing not only the expense incurred by failure, but also that too sudden an exposure of their success would attract the attention of rivals. It is difficult to exemplify to the House, how small and apparently unimportant an adaption of the parts of the Machinery, or of the mode of generating or applying the steam, may be the cause of the most rapid success; yet he who by a long course of experiment shall have first reached this point, may be unable to conceal the improvement, and others will at once reap the benefit of it.

"The Committee are convinced, that the real merits of this invention are such, that it may be safely left to contend with these and similar difficulties; there are others, however, from which the Legislature can alone relieve it. Tolls to an amount which would utterly prohibit the introduction of steam carriages, have been imposed on some roads; on others, the trustees have adopted modes of apportioning the charge, which would be found, if not absolutely prohibitory, at least to place such carriages in a very unfair position, as compared with ordinary coaches.

"Two causes may be assigned for the imposition of such excessive tolls upon steam carriages. The first a determination on the part of the trustees to obstruct, as much as possible, the use of steam as a propelling power; the second, and probably the more frequent, has been a misapprehension of their weight and effect on roads. Either cause appears to the Committee a sufficient justification for their recommending to the House, that legislative protection should be extended to steam carriages, with the least possible delay.

"It appears from the evidence, that the first extensive trial of steam as an agent in draught on common roads, was that by Mr. Gurney, in 1829, who travelled from London to Bath and back in his steam carriage. He states, that although a part of the Machinery which brings both the propelling wheels into action, when the full power of the engine is required, was broken at the onset, yet that on his return he performed the last eighty-four miles, from Melksham to Cranford Bridge, in ten hours, including stoppages. Mr. Gurney has given to the Committee very full details of the form and power of his engine, which will be found in the evidence.

Manufac-
tures.

"The Committee have also examined Messrs. Summers and Ogle, Mr. Hancock, and Mr. Stone, whose steam carriages have been in daily use for some months past on common roads. It is very satisfactory to find, that although the boilers of several engines described, vary most materially in form, yet that each has been found fully to answer the expectation of its inventor; so well in fact have their experiments succeeded, that in each case, where the proprietors have ceased to use them, it has only been for the purpose of constructing more perfect carriages, in order to engage more extensively in the business."

"When we consider that these trials have been made under the most unfavourable circumstances, at great expense, in total uncertainty, without any of those guides which experience has given to other branches of engineering; that those engaged in making them are persons looking solely to their own interests, and not theorists attempting the perfection of ingenious modes; when we find them convinced, after long experience, that they are now introducing such a mode of conveyance as shall tempt the Public by its superior advantages from the use of the admirable lines of coaches which have been generally established; it surely cannot be contended that the introduction of steam carriages on common roads is merely an uncertain experiment unworthy of legislative attention."

"Besides the carriages already described, Mr. Gurney has been informed, that from twenty to forty others are being built by different persons, all of which have been occasioned by this decided journey in 1829."

"The Committee have great pleasure in calling the attention of the house to the evidence of Mr. Farey. His opinions are the more valuable from his uniting, in so great a degree, scientific knowledge to a practical acquaintance with the subject under consideration. He states, that he 'has no doubt whatever, but that a steady perseverance in such trials will lead to the general adoption of steam carriages;' and again, 'that what has been done proves to his satisfaction the practicability of propelling Stage coaches (by steam) on good common roads, in tolerably level parts of the country, without horses, at a speed of eight or ten miles per hour.'

"Much of course must remain to be done in improving their efficiency, yet Mr. Gurney states, 'that he has kept up steadily the rate of twelve miles per hour; that the extreme rate at which he has run is between twenty and thirty miles an hour.'

"Mr. Hancock 'reckons that with his carriage he could keep up a speed of ten miles per hour without injury to the Machine.'

"Mr. Ogle states, 'that his experimental carriage went from London to Southampton, in some places at a velocity of from thirty-two to thirty-five miles an hour.'

"That they have ascended a hill, rising one in six, at sixteen and a half miles an hour, and four miles of the London road at the rate of twenty-four and a half miles per hour, loaded with people."

"That his engine is capable of carrying three tons weight in addition to its own."

"Mr. Summers adds, 'that they have travelled in the carriage at the rate of fifteen miles per hour, with nineteen persons in the carriage, up a hill one in twelve.'

"That he has continued for four and a half miles to travel at the rate of thirty miles per hour."

"That he has found no difficulty in travelling over the worst and most hilly roads."

Machinery

"Mr. James Stone states, 'that thirty-six persons have been carried in one steam carriage. That the engine drew five times its own weight, nearly at the rate of from five to six miles per hour, partly up an inclination.'

"The several witnesses have estimated the probable saving of expense to the Public from the substitution of steam power for that of horses at from one-half to two-thirds. Mr. Farey gives, as his opinion, 'that steam coaches will very soon after their first establishment be run for one-third of the cost of the present Stage coaches.'

"Perhaps one of the principal advantages resulting from the use of steam will be its being employed as cheaply at a quick as at a slow rate; this is one of the advantages over horse labour, which becomes more and more expensive as the speed is increased. There is every reason to expect, that in the end the rate of travelling by steam will be much quicker than the utmost speed of travelling by horses; in short, the safety to travellers will become the limit to speed. In horse draught the opposite result takes place: in all cases horses lose power of draught in a much greater proportion than they gain speed, and hence the work they do becomes more expensive as they go quicker. On this and other points referred to in the Report, the Committee have great pleasure in drawing the attention of the House to the valuable evidence of Mr. Davies Gilbert."

"Without increase of cost, then, we shall obtain a power which will insure a rapidity of internal communication far beyond the utmost speed of horses in draught; and although the performance of these carriages may not have hitherto attained this point, when once it has been established that at equal speed we can use steam more cheaply in draught than horses, we may fairly anticipate that every day's increased experience in the management of the engines will induce greater skill, greater confidence, and greater speed."

"The cheapness of the conveyance will probably for some time be a secondary consideration. If at present it can be used as cheaply as horse power, the competition with the former modes of conveyance will first take place as to speed. When once the superiority of steam carriages shall have been fully established, competition will induce economy in the cost of working them. The evidence, however, of Mr. M'Neil, showing the greater efficiency with diminished expenditure of fuel by locomotive engines on Railways, convinces the Committee, that experience will soon teach a better construction of the engines, and a less costly mode of generating the requisite supply of steam."

"Nor are the advantages of steam power confined to the greater velocity attained, or to its greater cheapness than horse draught. In the latter, danger is increased in as large a proportion as expense, by greater speed. In steam power, on the contrary, there is no danger of being run away with, and that of being overturned is greatly diminished. It is difficult to control four such horses as are able to draw a heavy carriage ten miles per hour, in case they are frightened, or choose to run away; and for quick travelling they must be kept in that state of courage, that they are always inclined for running away, particularly down hills, and at sharp turns of the road. In steam, however, there is little corresponding danger, being perfectly controllable, and capable of exerting its power in reverse in going down hills. Every witness examined has given the fullest

Manufac-
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and most satisfactory evidence of the perfect control which the conductor has over the movement of the carriage. With the slightest exertion it can be stopped or turned, under circumstances where horses would be totally unmanageable.

"The Committee have, throughout their examinations, been most anxious to ascertain whether the apprehension very commonly entertained, that an extensive use of these carriages on roads would be the cause of frequent accidents and continued annoyance to the Public, were well founded.

"The danger arising from the use of steam carriages was stated to be twofold: that by which passengers are exposed from explosion of the boiler and the breaking of the Machinery; and the effect produced on horses by the noise and appearance of the engine.

"Steam has been applied as a power in draught in two ways: in the one, both passengers and engine are placed on the same carriage; in the other, the engine carriage is merely used to draw the carriage in which the load is conveyed. In either case, the probability of danger from explosion has been rendered infinitely small, from the judicious construction of the boiler which has been adopted.

"These boilers expose a very considerable surface to the fire, and steam is generated with the greatest rapidity. From their peculiar form, the requisite supply of steam depends on its continued and rapid formation; no large and dangerous quantity can at any time be collected. Should the safety valve be stopped, and the supply of steam be kept up in greater abundance than the engines require, explosion may take place, but the danger would be comparatively trifling, from the small quantity of steam which could act on any one portion of the boilers. As an engine invented by Mr. Trevethick has not been as yet applied to carriages, the Committee can do no more than draw the attention of the House to the ingenuity of its contrivance. Should it in practice be found to answer its expectation, it will remove entirely all danger from explosion. In each of the carriages described to the Committee, the boilers have been proved to a considerably greater pressure than they can ever have to sustain.

"Mr. Farey considers that the danger of explosion is less than the danger attendant on the use of horses in draught; that the danger in these boilers is less than in those employed on the Railway, although there even the instances of explosion have been very rare. The danger arising to passengers from the breaking of the Machinery needs scarcely to be taken into consideration; it is a mere question of delay, and can scarcely exceed in frequency the casualties which may occur with horses.

"It has been frequently urged against these carriages that wherever they shall be introduced, they must effectually prevent all other travelling on the road, as no horse will bear quietly the noise and smoke of the engine.

"The Committee believe that these statements are unfounded. Whatever noise may be complained of, arises from the present defective construction of the Machinery, and will be corrected as the makers of such carriages gain greater experience. Admitting even that the present engines do work with some noise, the effect on horses has been greatly exaggerated. All the witnesses accustomed to travel in these carriages, even on the crowded roads adjacent to the metropolis, have stated,

that horses are very seldom frightened in passing. Mr. Machinery Farey and Mr. M'Neil have given even more favourable evidence, in respect to the little annoyance they create.

"No smoke need arise from such engines. Coke is usually burned in locomotive engines on Railways to obviate this annoyance; and those steam carriages which have been hitherto established also burn it. Their liability to be indicted as nuisances will sufficiently check their using any offensive fuel.

"There is no reason to fear that steam will cause much annoyance. In Mr. Hancock's engine, it passes into the fire; and in other locomotive engines it is used in aid of the power, by creating a quicker draught, and more rapid combustion of the fuel. In Mr. Trevethick's engine it will be returned into the boiler.

"The Committee not having received evidence that gas has been practically employed in propelling carriages on common roads, have not considered it expedient to inquire as to the progress made by several very scientific persons, who are engaged in making experiments on gases, with the view of procuring a still cheaper and more efficient power than steam.

"The Committee having satisfied themselves that steam has been successfully adopted as a substitute for horse power on roads, proceeded to examine whether tolls had been imposed on carriages thus propelled, so excessive as to require legislative interference; and also to consider the rate of tolls by which steam carriages should be brought to contribute, in fair proportion with other carriages, to the maintenance of the roads on which they may be used.

"They have annexed a list of those local Acts in which tolls have been placed on steam, or mechanically-propelled carriages.

"Mr. Gurney has given the following specimens of the oppressive rates of tolls adopted in several of these Acts. On the Liverpool and Prescott roads, Mr. Gurney's carriage would be charged £2. 8s., while a loaded Stage coach pays only 4s. On the Bathgate road, the same carriage would be charged £1. 7s. 1d., while a coach drawn by four horses would pay 5s. On the Ashburnham and Totness road, Mr. Gurney would have to pay £2, while a coach drawn by four horses would be charged only 3s. On the Teignmouth and Dawlish roads, the proportion is 12s. to 2s., which exorbitant tolls on steam carriages can only be justified on the following grounds.

"First, because the number of passengers conveyed on or by a steam carriage will be so great as to diminish (at least to the extent of the difference of the rate of toll) the total number of carriages used on the road; or, secondly, because steam carriages induce additional expense in the repairs of the road.

"The Committee see no reason to suppose that, for the present, the substitution of steam carriages, conveying a greater number of persons than common coaches, will take place to any very material extent; and as to the second cause of increased charge, the trustees, in framing their tolls, have probably not minutely calculated the amount of injury likely to arise from them.

"The Committee are of opinion, that the only ground on which a fair claim to toll can be made, on any public road, is to raise a fund, which, with the strictest economy, shall be just sufficient, first, to pay the expense of its original formation; secondly, to maintain it in good and sufficient repair.

"Although the Committee anticipate that the time is

Manufac-
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not far distant, when, in framing a scheme of toll for steam carriages, their general adoption, and the great number of passengers which will be conveyed on a small number of vehicles, will render it necessary, not only to consider the amount of injury actually done to the road, but also the amount of the debt which may have been incurred for its formation or maintenance; yet at present they feel justified, by the limited number of such carriages, and by the great difficulties they will have to encounter, in recommending to the House, that, in adopting a system of toll, the proportion of wear and tear of roads by steam, as compared with other carriages, should alone be taken into consideration.

"Unless an experiment were instituted on two roads, the one reserved solely for the use of steam coaches, the other for carriages drawn by horses, for the purpose of ascertaining accurately the relative wear of each, it would be quite impossible to fix, with certainty, the proportion of tolls to which, on the same road, each class of vehicles should be liable. To approximate, however, as nearly as possible to the standard of relative wear, the Committee have compared the weights of steam carriages with those of loaded vans and Stage coaches. They have tried to ascertain the causes of the wear of roads; also the proportion of injury done by the feet of horses and the wheels of coaches; how far that injury is increased by increased velocity; and also in what degree the wear of the roads by loaded carriages may be decreased by any particular form of wheel.

"The Committee would direct the attention of the House especially to the evidence of Mr. M'Neil, whose observations on this branch of the subject being founded on a long course of very accurate experiments, are peculiarly interesting and useful. He estimates that the feet of horses, drawing a fast coach, are more injurious to the road than the wheels, in the proportion of three to one nearly; that this proportion will increase with the velocity; that by increasing the breadth of the tires of the wheels, the injury done to roads by great weights may be counteracted. He considers that, on a good road, one ton may be safely carried on each inch of width of tire of the wheels.

"Mr. M'Adam and Mr. Telford have given corresponding evidence, as to the greater wear caused by horses' feet than by wheels of carriages.

"Each of the above witnesses agrees, that, adding the weight of the horses to that of the coach, and comparing the injury done to a road by a steam carriage of a weight equal to that of the coach and horses, (the wheels being of a proper width of tire,) the deterioration of the road will be much less by the steam carriage than by the coach and horses.

"As to the injury to roads, which is anticipated from the slipping of the wheels, it may safely be left to the proprietors to correct; the action of the wheels slipping, involves a waste of power, and a useless expenditure of fuel, which, for their own sakes, they will avoid.

"Apprehension has also been entertained, that, although the peculiar action of the wheels may not be injurious, yet that, from the great power which may be applied, if the steam were worked at very high pressure, or if the size of the engine were increased, greater weight might be carried than the strength of the road could bear.

"Undoubtedly, in proportion to the advance of the Science, will be the increase of weight drawn by an engine with a given expenditure of fuel; but there are

many practical difficulties to be surmounted, before the weight so drawn can reach the point, when it would be destructive of roads. There are no theoretical reasons against the extension of the size of the engines. The difficulties, according to Mr. Gurney, are of a practical nature, and only in the difficulty of management of a large engine. In proportion as we augment the power of the engines, we must increase their strength, and, consequently, their weight; the greater weight will be a material diminution of their efficacy. To a certain extent, the power may be increased in a greater ratio than the weight; but, with our limited knowledge of the application of steam, and with the present formation of the public roads, the point will be very soon attained, when the advantage of increased power will be counterbalanced by the difficulties attendant on the increased weight of the engines.

"The weight of the steam carriages at present in use varies from fifty-three to eighty hundred weight; but it must be recollected that they are mere models; they were made with attention to strength only, to bear the uncertain strain to which they would be exposed in the course of experiments, and a very considerable diminution of weight may be anticipated.

"The weight drawn, at the rate of ten miles per hour, by Mr. Gurney's engine, has not, on any extent of road, exceeded the weight of the drawing carriage; nor is it likely, with the difficulties to be encountered on the present lines of road, from the quality of the numerous ascents, that the weight drawn will be in excess of the strength of the roads. The immense quantity of spare power required to surmount the different degrees of resistance likely to occur, would render the engine too unmanageable. This will appear evident from the force of traction required to draw a waggon over the Holyhead and Shrewsbury road, which varies from forty to upwards of three hundred pounds.

In considering the effect on roads, we must not overlook one peculiarity, in which they have a great advantage over other carriages. In coaches drawn by horses, the power being without the Machine to be moved, it becomes an object of the greatest importance to give as much effect as possible to the power by diminishing the resistance arising from the friction of the wheels upon the surface of the road. For this purpose, the proprietors of coaches and waggons have adopted every possible contrivance so to reduce the tires of their wheels, that a very small portion of them may press on the road; in some coaches they are made circular in their cross section, so that the entire weight of the carriage presses on a mere point. Should the materials be soft, such wheels cut their way into the road like a sharp instrument. The owners of waggons, too, have adopted a similar plan: Mr. M'Neil states, that the actual bearing part of the tire of apparently broad wheel waggons, is reduced to three inches, by the contrivance of one band of the tire projecting beyond the others.

"With steam, on the contrary, a certain amount of adhesion to the roads is required to give effect to the action of the Machinery, or the wheels would slip round, and make no progress. It appears of little importance, therefore, so far as relates to the engine, whether the requisite amount of friction be spread over a broad surface of tire, or be concentrated to a small point; but as the wheels, by being too narrow, would have a tendency to bury themselves in every soft or newly made road, and thus raise a perpetual resistance to their own pro-

Machinery.

Manufac-
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gress, it actually becomes an advantage to adopt that form which is least injurious to the road. The proprietors who have been examined on this point seem to be quite indifferent as to the breadth of tire they may be required to use.

"These considerations have convinced the Committee that the tolls enforced on steam carriages have, in general, far exceeded the rate which their injuriousness to roads, in comparison with other carriages, would warrant; they have found, however, considerable difficulty in framing a scale of tolls applicable to all roads, in lieu of those authorized by several local Acts.

"With this view, they have carefully examined the various modes of imposing tolls, either suggested by the witnesses, or already adopted.

"They are as follows:

"1. To place a toll proportioned to the weight of the carriage and load.

"2. On the number of passengers.

"3. On the horse power of the engine.

"4. On the number of wheels.

"5. On unvarying toll.

"Each of these plans seems liable to serious objections, which the Committee beg to submit to the House.

"No plan of toll has been more frequently recommended than that of a charge in proportion to the weight of the engine and load. As this is the most plausible, and (if it could be levied without other disadvantages) would probably be the fairest standard, the Committee have considered it right to state, at some length, their reasons for not recommending its adoption.

"If weight be taken as the standard, the toll must be a fixed charge, either upon the weight of the engine and carriage, without reference to the load; or, upon an estimated average of the load carried; or, a fluctuating charge, according to the weight at the several periods of a journey.

"The first would be at least free from the uncertainty of the other two, and therefore would be preferable; but what scale of charge per hundred weight could the Committee recommend as applicable to all roads? Their toll should vary according to every different rate of charge on carriages; besides, it would appear to the trustees very unjust to exclude the consideration of that which would be deemed the most material cause of the wear of their roads; viz. the load.

"A fluctuating charge on weight would be most injurious to a carriage, which will mainly depend for success on its speed; constant altercations would take place between the toll collectors and proprietors; a minute calculation would be required at every turnpike-gate; in fact, unless an accountant were placed at each, the Committee cannot conceive how the proportions could be satisfactorily arranged; nor would there be any desire, on the part of the toll collector, to shorten the delay occasioned by these interruptions.

"Mr. Gurney has delivered in a scale of tolls, graduated according to the weight and width of tire of the wheel. As this has been drawn up by a person interested in the success of steam carriages, it might have been expected to be more favourable to them. The Committee, however, have not adopted it, because of the difficulties and interruptions which a fluctuating rate of toll would induce; besides, this scale purports to be intended for a road, where three-pence is charged for a horse drawing and one penny for a horse not drawing; the scale would be inapplicable, therefore, when

the charge was two-pence and one penny, three-pence and three half-pence, four-pence and one and four-pence, and three half-pence, eight-pence, and so on. Again, what standard of weight in relation to horse coaches, could be adopted? The average weight of loaded coaches differs very much on different roads. It has been suggested that a loaded coach, including the weight of four horses, would weigh on an average four tons, and that if six-pence per horse were chargeable to the coach, six-pence per ton should be placed on a steam carriage; this would be unjust, as vans, which frequently weigh upwards of six tons, would only pay two shillings and a steam carriage would pay three shillings. Even if the injury done to the road by each were equal, this would be an unfair toll; but it will appear more evidently unjust if the greater proportionate injury done by the feet of horses drawing, than by the propelling wheels, be taken into consideration.

"The object of every steam coach proprietor will be to attain the greatest possible lightness of Machinery and engines; because thereby he renders his power more efficient for the draught of the remunerating load. To place the toll on the weight of the engine would tend to induce him to decrease the strength of his boiler and Machinery to an extent which might be dangerous to the passengers, and very detrimental to the success of steam travelling, as the Public will easily be led to believe that accidents really occurring from injudicious legislation, were inseparable from the adoption of this power as an agent in propelling carriages.

"The only fair plea for charging tolls on such carriages, in proportion to their weight, is to prevent a load being propelled or carried which would permanently injure the road; within this limit it would be as injudicious to interfere with their progressive efficiency, (which can only result from improvements of the Machinery and the system of generating and applying steam,) as it would be to tax carriages drawn by large and well-bred horses more heavily than such as were drawn by horses in worse condition and of smaller size and power.

"The roads at present have to sustain waggons, weighing at times, with their horses, nearly ten tons; it is in evidence that the breadth of wheels required by various Acts of Parliament is so easily evaded, that it affords no protection to the road. There appears to the Committee no fair reason to suppose, that steam carriages, approaching even to its weight, will be used on any turnpike-road, at least for a very considerable period, during which the increase of weight will be gradual, and will give ample warning to the Legislature when it should interfere.

"To charge a toll according to the number of passengers conveyed is scarcely less objectionable. If a fluctuating toll be intended, it would be as inadmissible as to propose a similar mode of charging for fast coaches, and would be open to all the cavil and interruptions to which a fluctuating toll on weight would be liable. If the toll were fixed according to the number of passengers the carriage were capable of conveying, it would imply the necessity of a license, limiting the number of passengers and cramping the progress of improvement to a Machine, the capabilities of which can only be ascertained slowly, and by continued experiment.

"It must be also recollected, that these carriages will probably have to travel for a long period without passengers, until by their punctuality and safety they shall

Machinery.

Manufactures.

have induced the public to venture in them. Nor is this probability weakened by the immense number of passengers who commenced using the locomotive carriages on the Manchester and Liverpool Railway, immediately after their introduction. These engines were established amongst a population accustomed to Machinery and steam, and therefore not entertaining the same apprehensions of its danger which will require to be surmounted elsewhere.

"The Trustees of the Liverpool and Prescott road have already obtained the sanction of the Legislature to charge the monstrous toll of one shilling and sixpence per horse power, as if it were a national object to prevent the possibility of such engines being used. Besides, they have supplied no standard of their own conception of horse power. Engineers have differed very much in their estimates of this power; there is not, therefore, much probability that the opposite interests of a steam coach proprietor and toll collector would lead to any agreement as to the meaning of the term. But suppose the Legislature were to settle this point, and to arrange that a certain length of stroke and diameter of cylinder should represent a certain power, we still fail to ascertain that which alone it is essential to know, viz. the actual efficiency of the engine. Can we regulate the density of steam at which an engine of a given size should be worked? To be effectual, it would be also necessary to ascertain the quantity of water consumed; and even this check would be inadequate with an engine on Mr. Trevethick's principle. If the toll be left as at present on horse power, it would be the obvious interest of the proprietor to work with the smallest nominal power, but to increase as much as possible the force of his steam, thereby increasing the probability of explosion.

"Some Trustees have placed the toll upon the number of wheels. The Committee would object to this mode of charge, if only because it interferes between the rival modes of steam travelling, and gives a bounty in favour of that in which the engine is placed on the same carriage with the passengers. The opposite plan of separating the engine from the carriage is that which probably the Public will prefer, until the safety of the mode of conveyance shall have been fully ascertained.

"There is still a more serious objection to this mode of charge: it tends to discourage the use of separate carriages; although it must be evident, that if a certain weight be carried, it will be much less injurious to the road when divided over eight wheels, than when carried on four only. On this point the Committee must again refer to Mr. M'Neil's evidence. They cannot, therefore, recommend the House to adopt a scale of toll which shall increase in inverse proportion to the injury done to the road. It will be seen in Mr. M'Adam's evidence, that the toll on steam coaches, imposed by the Metropolitan Road Act, is liable to this objection.

"Some of the local Acts have placed an unvarying toll on steam carriages. This, if moderate, would be unobjectionable; but the Committee could not propose any sum which would adapt itself to the necessary varieties of expense in keeping up different roads, by which the tolls on common carriages have been regulated. A fixed toll has, too, this disadvantage, that light, experimental carriages, or such as are built solely for speed, could be liable to the same toll as steam carriages heavily laden.

"The Committee feel that, however strong their con-

viction may be of the comparatively small injury which properly constructed steam carriages will do to the roads, yet this conviction is founded more on theory, and, perhaps, what may be considered as interested evidence, than practical experience; they would therefore recommend, that the House should not make, at present, any permanent regulations in favour of steam. The experience which will be gained in a very few years, will enable the Legislature to form a more correct judgment of the effect of steam carriages on roads, than can be now made. They therefore recommend, that the tolls imposed on steam carriages by local Acts, where they shall be unfavourable to steam, shall be suspended during *three years*; and that in lieu thereof, the Trustees shall be permitted to charge toll according to the rate to which the Committee have agreed.

"The House will have perceived, in the former part of this Report, that there are two modes of applying steam in lieu of horses in draught: one where the engine and passengers are on the same carriage; the other where the engine is placed on separate wheels, and is merely used to propel or draw the carriage. Although the difference of weight may be in favour of the former mode, yet, as on the latter it is divided over eight wheels instead of four, its small excess cannot justify a larger toll being imposed, as it will be found much less injurious to the roads. The Committee therefore recommend that, in charging tolls, the engine carriage and carriage drawn shall be considered but as one.

"As it is the opinion of all the engineers examined, that the use of narrow wheels has been the great cause of the wear of roads, and that cylindrical wheels, of a certain width of tire, are not only the least injurious, but that in some states of the road they may be even beneficial, the Committee recommend that the wheels of the engine carriage should be required to be cylindrical, and not less than three inches and half width of tire. No proprietor of steam carriages has expressed the slightest fear of any inconvenience or loss from the use of such wheels. Beyond this, the Committee would not recommend interference with the breadth of tire or form of wheels; it should be left to the proprietors freely to select the breadth of tire they shall find most convenient, in proportion to the weight carried.

"The Committee have divided steam carriages (intended for passengers) into two classes, to be subject to different rates of tolls. The first, where the carriage is not plying for hire, or where, if plying for hire, it shall not be calculated for, or carry at any time more than six passengers: the original cost of such Machines, and the expense of working them, will sufficiently protect the roads from any great number of merely experimental carriages; and for the same reason they will not be of a weight or size likely to be injurious. A steam carriage only calculated to convey six passengers will be solely used where great speed is required, and will be so light, as to cause very little wear of the road, probably much less than many carriages drawn by the number of horses which the Committee recommend as the standard of charge for this class. The toll, therefore, proposed to be placed on this class of steam carriages, is that which (on the several roads where they may be used) is charged on a carriage drawn by two horses.

"In the second class, they have placed all other steam carriages, except those travelling at slow rates for goods only. Carriages of this class should pay the same toll as may be charged on a coach drawn by four horses.

Manufac-
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This may at first appear unjust, from the supposed power of steam to draw almost unlimited weight. The Committee have already enumerated the difficulties hitherto encountered in attempting to propel very heavy loads on turnpike roads. They are such as to discourage the expectation that, within any short period of time, the system will have been so perfected as to give rise to inconvenience from this source; should any hereafter be found, it will then be sufficient to remedy the defect. Until a due proportion of the parts of the Machinery shall have been ascertained, the makers of these carriages will vary but cautiously from the models at present in use; their object will be, for some time, the perfecting of them, rather than the uncertain experiment of increasing their size.

"The Committee do not anticipate that, for a considerable period, steam will be used as a propelling power on common roads for heavy waggons. It appears to have been the general opinion of the witnesses, that in proportion as the velocity of travelling by steam on common roads is diminished, the advantages of steam over horse power are lost. The efficiency of horses in draught is rapidly diminished as their speed is increased; while, on the contrary, the weight which could be carried or propelled at any great velocity by steam, could not be more cheaply conveyed, were the speed decreased to that of the slowest waggon.

"As speed, therefore, is the cause of greatly increased expense where horses are used, while with steam it is comparatively unimportant, it is probable that the latter will be chiefly resorted to when rapidity of conveyance is required. Mr. Gurney considers that, under four miles per hour, horses can be used in draught more economically than steam. Should it, however, be deemed profitable to convey heavy goods by steam carriages, the Committee recommend that there should be as little interference as possible with the number of carts employed; as the effect on the surface of roads would be infinitely more injurious if heavy loads were placed on a single cart, than if the same weight were divided over several. The Committee recommend, that where carriages, containing heavy goods alone, are propelled by steam, the weight of the load should be charged, without reference to the number of carts on which it may be carried.

"As a horse is able to draw from twenty to forty hundred weight on common roads, they propose that each twenty hundred weight of load conveyed in or drawn by a steam carriage, should be chargeable at the same rate of toll as one horse drawing a cart.

"A charge on weight is not so objectionable where goods are conveyed at a slow rate, as when speed is alone required.

"In conclusion, the Committee submit the following summary of evidence, given by the several witnesses, as to the progress made in the application of steam to the purposes of draught on common roads.

"Sufficient evidence has been adduced to convince your Committee,

"1. That carriages can be propelled by steam on common roads at an average rate of ten miles per hour.

"2. That at this rate they have conveyed upwards of fourteen passengers.

"3. That their weight, including engines, fuel, water, and attendants, may be under three tons.

"4. That they can ascend and descend hills of considerable inclination with facility and safety.

"5. That they are perfectly safe for passengers.

"6. That they are not (or need not be if properly constructed) nuisances to the Public.

"7. That they will become a speedier and cheaper mode of conveyance than carriages drawn by horses.

"8. That as they admit of greater breadth of tire than other carriages, and as the roads are not acted on so injuriously as by the feet of horses in common draught, such carriages will cause less wear of roads than coaches drawn by horses.

"9. That rates of toll have been imposed on steam carriages, which would prohibit their being used on several lines of road, were such charges permitted to remain unaltered."

(316.) Since the above Report was made, the practice of road locomotives has been persevered in, and with considerable success; but we cannot in this place enter into a minute description of the journeys that have been taken, nor all the changes which these carriages have undergone in the hands of different engineers; but we shall avail ourselves of a very ingenious Work on *Locomotion by means of Steam Carriages on common Roads*, by Alex. Gordon, Civil engineer, to give a description of one of those engines which have made the most successful experiments in this practice. Before entering upon this, however, it may be well to state a few particulars respecting some more early claims to the invention than are referred to in the preceding Report. It appears that Dr. Robison, in 1759, at that time a student at Glasgow, and the celebrated Watt had some faint ideas on the subject of employing steam for producing locomotion; and that this speculation, which was Dr. Robison's, led to the first acquaintance of these two distinguished individuals. It does not appear, however, that any attempts were made beyond mere suggestions.

In 1772, Oliver Evans, an ingenious American, made some experiments on this subject, and continued to make different trials till 1786, when he petitioned the Legislature of Pennsylvania for his exclusive right to use his improvements in flour-mills and steam waggons in that State.

Within this interval, 1784, Mr. Symington of Falkirk projected a locomotive engine for common roads, and made a small model to illustrate the nature of its action; and the inspection of this model, as we have seen in the History of Steam Navigation, induced Mr. Millar to order Mr. Symington to construct for him two engines, on somewhat similar principles, to be applied to steam vessels. In the same year, 1784, Mr. Watt took out a patent, amongst other improvements in the steam engine, for a mode of applying it to wheel carriages. Scarcely any thing, however, resulted from these projections; but in the year 1802, Mr. Trevethick invented a high pressure engine and boiler in one Machine, and made several experiments in and about the metropolis, on its power as a road locomotive, but failed in bringing it to perfection for that purpose. It was afterwards applied as a locomotive on a Railway, at Merthyr Tidvil, as already stated in a preceding page.

In 1821, Mr. Griffiths had a steam carriage constructed by Messrs. Bramah and Sons, which was intended to work on a good turnpike road. It is stated by Mr. Gordon to have been very perfect in all the adaptations of the mechanical parts, and that it failed only from a defective principle in the construction of its boiler.

Machinery

First attempts at working locomotives on roads.

Manufac-
tures.

In 1822, a patent for a locomotive steam carriage was taken out by Mr. David Gordon, and a second in 1824; but in both these the motion was given by propellers, somewhat similar in principle to that of Mr. Brunton, already referred to (Art. 302.)

The use of propellers was, however, at this time found to be unnecessary; and we come now to the time when the locomotive engine for common roads began to assume a more promising character, and to be occasionally exhibited in Public. Passing over the two patents of Messrs. John and Samuel Seaward, and of Messrs. Hill and Burstall, we come to Mr. Gurney, who, in 1825, produced a specimen of this species of engine, which offered so many grounds for hopes of ultimate success, that to him and his unwearied perseverance we are (as stated in the preceding Parliamentary Report) mainly indebted for the progress made in this practice. Without stopping to describe this carriage, we proceed to Mr. Gurney's second patent, in 1827. Under this patent he worked with a steam carriage resembling, in external appearance, a common Stage coach, the boiler being situated in the hind boot; in the front boot a blower, like the revolving fans of a winnowing Machine, moved round horizontally in a close box, from which a tube conveyed the blast to the coal ash-pit of the fire-place, and the hind wheels acted upon the cranks on the hind axle. The hind wheels had sockets or boxes in their centre, like common wheels, so that either of them might be made to run loose on the axle when required, but were fastened to the axle, so as to turn round with it when necessary. This was effected by means of a round plate, fitted on a hexagonal part at each end of the axle, and a similar plate fastened to the nave of each wheel, close to the former; screw bolts passed between the two plates, and, secured with nuts, gave the desired connection, which could again be withdrawn by removing the bolts.

Description
of boiler.
Pl. xxii.
Fig. 4, 5, 6.

(317.) But the great advantage which Mr. Gurney's contrivance has over others, consists in his boilers. This may be described as follows: pl. xxii. fig. 4, shows a section of one of these boilers; *a* is the point at which the water is pumped into the boiler; *b* the water level in the separator *E*. It will be observed that *A*, *B*, *C*, *D*, fig. 4, 5, 6, are all full of water. The fire is made at *F*, and plays through, around, and between these tubes. The hotter particles of water occasion a continuous flow from *A* through *C* to *D*; when they arrive at *D*, the colder particles descend through *B*, and again are drawn through the tubes *C*. These tubes, it will be seen, by their inclination, always offer an ascent for the hot particles and for the steam. By this arrangement the circulation is constant and complete, and the steam is rapidly given off at *E*, where it is ready for the engine. The chamber *E* is sometimes placed vertically, instead of horizontally; sometimes, also, there are two of these steam chambers *E* connected together, and to the engine; *G* is the fire door, and *H* the flue.

In the later coaches of the patentee's construction, he has discontinued a blast for urging the fire, and has used the waste steam to occasion the draught as described in (Art. 212.) This is effected by blowing the waste steam by several small jets upwards into the lower part of the chimney. The increase or decrease of draught is regulated by the size of the aperture through which is ejected. A very perfect draught is thus obtained, and the fire can be enlivened or damped according to the required speed of the engine. With a boiler containing

so small a quantity of water, and so large a proportion of heating surface, the facility of lessening or increasing the heat, and, consequently, the power of the steam, is very great; and this facility is highly important for economizing the fuel, and for the quick and certain management of the steam carriage on hilly or crowded roads.

Machinery

In 1831, Mr. Gurney having completed three carriages for Sir Charles Dance, that gentleman commenced running one of them regularly on the road between Gloucester and Cheltenham, and continued so to do constantly and successfully four months; until tired of the opposition and imposition of the turnpike trusts, he withdrew his carriage, and, at his suggestion, Mr. Gurney presented his Petition to Parliament on the subject of these tolls, which led to the appointment of the Committee, and the Report which we have given in a preceding page.

(318.) We have, as above stated, been indebted to Mr. Gordon for many of the preceding particulars; and from the same authority we have obtained the following description of one of the latest and most improved of Mr. Gurney's carriages. This is shown in the plate already referred to, fig. 1, 2, 3. *A* is the position of the boiler above described; *B* the steam pipe which passes under the body from the boiler, till it arrives at the point *N*, and from thence passes down to the valve boxes *CC*, of the cylinders *DD*; *NN* are fixed points, on which the body rises and falls, as on a hinge, when the spring above the hind axle has play. If the steam pipes were not brought close to this point, they could not be kept tight, as the play of the spring would disturb them, and occasion a leakage. *E* is the wheel of the parallel motion, which runs horizontally between the parallel bars *GG*. Through this wheel there is a spindle or axle, upon the ends of which a forked or double connecting rod *F* is attached, so that in the revolution of the crank *K* the parallel bars are inside the double connecting rod *F*. This is shown more distinctly in the plan, fig. 3, which exhibits the two engines at different parts of their stroke. At *H* is placed the water pump, each engine having a separate one; and each pump is worked by its connection with the piston rod of its corresponding engine. The valve motion is obtained from eccentrics on the crank shafts, outside the cranks. The valve rods will be easily distinguished at *mm*: at the extreme ends of the crank shafts, *i. e.* the hind axle of the drag, and between the spring and the wheel on each side, is shown the driving arm, marked *PP*, by means of which the power is conveyed from the crank shaft to the circumference of the hind wheel, so that one or both wheels may be used. It will be seen that the driving arm in the section being pressed up by the engine against the bolt, which is shown above it, must force the wheel in that direction, and thus propel the carriage forward, the friction or adhesion of the wheel on the ground serving as a fulcrum to the power. One or both of the hind wheels are thus used as occasion requires, for it is obvious if the bolt be withdrawn, the driving arm *P* will revolve without propelling the wheel; but as it is found in practice, that one wheel is sufficient for taking the carriage even up hill, the provision of the driving arm is seldom had recourse to. The part seen at *J* in the three figures will sufficiently explain how the carriage is turned. The pinion on the lower end of the rod *J* works in a rack, which is made fast to the front axletree, so that if the conductor, who sits on the box, turn the wheel (on

Description
of Mr. Gur-
ney's car-
riage.

Pl. xxii.
Fig. 1, 2, 3.

Manufac-
tures.

which his hand rests) to the right, the pinion will draw the rack round also to the right, and with it the front wheels, the same as if they were turned by horses, and with equal or greater facility and certainty. On the foot board is placed a lever L, which when pulled up by the conductor reverses the motion of the engines, and thus stops the carriage, or propels it backward if necessary. The body of the carriage is in the shape denominated by coachmakers a brisca; it is entirely used as a drag to another carriage which we may conceive attached at Q. No passengers are allowed to be in the drag; the coach-box being occupied by the conductor, and the interior by the boiler at A, and by the engineer, the fuel and water are at R. Upon the highest point of the steam pipe B B is a handle, which can be turned either by the conductor or by the engineer for the greater or less supply of steam. The chimney is placed in the back of the body, and is so constructed that it cannot be seen by the horses on the road. The water for the boiler is introduced into the tanks through a funnel which resembles a dicky on the hind boot.

When the carriage is to be started, the steam being already got up, the conductor, who sits ready on the box, opens the steam cock by the lever or handle at his side; the steam then finds its way along B B, to the cylinders D D, the action of the engine then commences, and the carriage is urged forward on its proposed journey. We cannot in this place enter into further description of locomotive engines for common roads, although various other principles, both in form and construction, are certainly highly deserving of particular detail; such are the carriages of Mr. Hancock, of Mr. Gibbs, of Messrs. Sommers and Ogle, &c.; but for these we must be content to refer the reader to Mr. Gordon's Treatise already referred to, also to the *Mechanics' Magazine*, which has occupied much space in the description of these vehicles, and to the *Journal of Elemental Locomotion*, devoted almost entirely, as its title imports, to this subject.

SIMPLE AND COMPOUND MACHINES.

Definition
of Engines,
Machines,
Mills, &c.

(319.) In the preceding part of this Treatise we have illustrated the nature of the several first movers, explained the elementary parts of Machinery, and their modes of communication, treated of several classes of mills, so far as regards the means employed to produce a first rotation, and whose denomination is derived from those means, as hand-mill, wind-mill, water-mill, &c., including the steam engine. We have also shown the application of the latter to mining, navigation, and locomotion; but it still remains to treat of the Machines put in motion by the elementary forces and rotations thus obtained. As far as we have hitherto described the wind or water-mill, no ulterior object is involved. The first motion being produced, we may employ it to grind corn, to spin cotton, to pump water, to roll iron, or to effect any other mechanical object; and our business now is, to describe the Machines, both simple and compound, by which those objects are obtained.

In the present state of Arts and Manufactures in this Country, where almost every mechanical process is effected by Machinery, it is difficult to classify the subjects in this division of our Work; and the classification also, necessarily, is somewhat arbitrary. The same construction being sometimes called an Engine, a Machine, or a Mill.

We shall, however, endeavour in this respect to conform as nearly as possible to the common language of the Arts; but if, after all, a Machine should not be found under the head by which it has been commonly known to the reader, we must trouble him to refer to some of the other heads; and sometimes the description of a Machine may be found under that of the Manufactures or Manufactory in which it is employed. Such references, however, will be avoided as much as possible; but it must be obvious, that where the same thing is known by different names in different Counties, and even in the same County or town, it is impossible to avoid them entirely.

With respect to the two terms, Engine and Machine, there is very little if any distinction to be discovered in their original signification; and a mechanical construction has been, therefore, called the one or the other according to the caprice of the inventor; but the term Mill has certainly a more distinct original meaning, denoting a Machine employed in the process of grinding. It afterwards took a more extended signification, *i. e.* any Machine used in crushing or pressing by a rotary motion; such are the sugar-crushing mill, the sugar-cane mill, stamping mill for ores, oil-mills, &c., and lastly, it was applied to nearly every Machine worked either by wind or water as a first mover. This, undoubtedly, arose from confounding the means employed to produce rotation with the operation performed by it. In early times, wherever a water wheel was at work, its business was grinding, and the whole was properly a mill; but as the Arts advanced, the rotation produced by the power of the water was employed for various purposes, and the denomination of mill remained, although in many cases very improperly, as in those of silk-mill, cloth-mill, cotton-mill, &c. These obvious improprieties will be avoided in our classification; but for the rest it is, perhaps, more desirable to arrange the several Machines according to the denomination under which they are generally known, than by a critical distinction as to their proper designation, to confuse the reader by unnecessary references from one head or class to another.

It may also be well to observe, that in treating of some Machines it will be convenient to describe the preparation of the material previous to its entering the same, and the nature and application of its produce; while in others the simple operation only can be illustrated, and the subsequent processes will be treated of under some distinct head of Manufacture. It is hoped, however, that any inconvenience which might thus arise to the reader, will be in a great measure obviated by the copious alphabetical Index given at the end of the volume.

Engines.

(320.) It has been already remarked, that the distinction between what is denominated an Engine, and what is called a Machine, is very arbitrary; unless, indeed, we consider as properly falling under the former class those Machines in which great exactitude of operation is required. Such, for example, as are employed in cutting screws, particularly original screws, dividing mathematical and astronomical instruments, which are, we believe, universally called Engines. But besides these, we have pile-driving Engine, fire Engine, &c., which require no extraordinary accuracy, either in their construction or use; so that, in fact, we must consider the two terms as

Engines.

Manuf-
tures.

implying no kind of distinction except so far as custom has prevailed in appropriating the one or the other to particular mechanical contrivances; and conforming also to custom in this respect, we shall, under this head, describe a few Machines which are more generally spoken of under the designation of Engines.

Cutting Engines.

(321.) Under this head are classed all those Machines employed in cutting various materials into particular figures, or for particular purposes, such as those used in cutting combs, screws, teeth of wheels, files, &c. These, as we have observed above, are sometimes called Engines and sometimes Machines. It is proposed here to describe them under the former designation.

Engine for
cutting
combs.

Engine for cutting combs.—In preparing the material of which combs are formed, some preliminary operations are required, which, however, it is not necessary to describe in this place, as it consists only in sawing the ivory, wood, &c., into their laminæ, either by hand or by a circular saw.

Materials for combs are box-wood, ivory, horn, and tortoise-shell. These being cut into pieces of the proper size, and the general form of the comb having been given to them by common tools, such as rasps, scrapers, &c., the next and most important part of the process is cutting the teeth.

This was formerly done, in all cases, by means of a double saw, consisting of two parallel blades, one of them being deeper than the other, so that when the deepest blade has cut to the whole depth of a tooth, the other shall have cut only to the depth of half a tooth. In using it, the deep blade makes the first cut at a little distance from the outside of the material, so that by the first action of the saw the outer side of one tooth and half the inner side of the same tooth are cut. The saw is then advanced one tooth so that the deep saw rests in the cut made by the shallow saw, while this latter is ready to form half the outside cut of the second tooth. Thus the saw is advanced a tooth at a time, the intervals between the teeth are rendered equal, and half the cut for the deep saw being already made, the tool is prevented from swerving, or cutting teeth of unequal thickness.

Soon after the invention of the circular saw, it was applied to comb cutting, by fixing on one axis two circular saws, one of greater diameter than the other, and regulating the distance between them according to the fineness of the teeth to be cut. Both the straight and circular double saws are now in use; the former being still applied to cutting combs out of all the four above-mentioned materials, the latter being used chiefly for combs of box and of ivory. Boxwood and ivory, subjected to the perpendicular action of a cutter, would break and splinter; but horn and tortoise-shell being of a laminated texture, and capable of being rendered soft and flexible by heat, will yield in this state to the action of a sharp vertical cutter without splintering.

Mr. Rick-
etts's en-
gine.

(322.) About twenty years ago, the principal house in London at that time for the sale of combs had received from abroad some patterns of ornaments, like the spikes and balls of coronets, to be attached to tortoise-shell combs. They gave the order to execute these to an ingenious artist of the name of Ricketts, who contrived a punch, by the successive pressure of which on a thin piece

of warm tortoise-shell, he cut out the pattern, piece by piece. On disengaging the pattern from the other part, he observed to himself, here are two combs cut out of the material for only one.

Improving on this hint, he soon contrived an engine, in which a single cutter descended vertically, being put in motion by a treadle and wheel; the bed on which the tortoise-shell was fastened was notched at the side, and these notches fitted into and corresponded with those of a rack placed parallel with it. After every cut, the bed was moved forward by hand the distance of a single notch, and thus an equal interval between all the cuts was secured. But the form of the tooth of a comb being that of a very long triangle, it was necessary that, as the bed was shifted forward, notch by notch, there should also be an alternate motion given to the bed; this likewise was given by hand: thus the first rude attempt at parting combs, *i. e.* for cutting one set of teeth out of the intervals of another set, was completed.

When the knowledge of this engine began to spread abroad, various contrivances were invented to advance the bed, and give the necessary alternate change in direction by Machinery. In some cases this alternation was given to the bed, in some to the cutter itself.

Previously to this time, however, it had occurred to the original inventor, Mr. Ricketts, that the Machinery necessary to produce this alteration of direction might be dispensed with, by making the cutter double, *i. e.* composed of two blades set obliquely, so as nearly to touch at one end, and the other to be as far apart as the width of a tooth; at the same time the blades made a return at their ends to liberate the extremities of the teeth.

It is evident that, while the cut is making, the material must be stationary, and that in the interval between the rise and descent of the cutter, the bed must have advanced the breadth of a tooth. This was effected in Mr. Ricketts's double cutting engines by working the cutter alone by a treadle, and advancing the bed by a screw, to the end of which a winch was fastened, so that one complete or one half turn gave the necessary advance, a pause being made after each turn or half turn, to bring the bed to a stop while the cutter was in action.

(323.) Mr. Rogers's engine obtains this end without the use of a treadle, by means of a single winch. The axis to which the winch is fixed gives motion to the cutter by means of a crank, and on the axis is a wheel having part of the cogs removed; this wheel takes into a common cog-wheel on the axis of a screw, by the turning of which the bed with the work on it is moved forwards. Hence it is evident, that while the Machinery for raising and lowering the cutter is in constant action, as long as the winch is turned, the screw which gives motion to the bed is still and out of action, during that part of the revolution of the winch in which the cogs of the two wheels are not bearing on each other. By enlarging the space from which the cogs of the second wheel are cut, the interval between one tooth and another is diminished; so that any given distance of teeth may be obtained by putting on to the axis of the screw a wheel with the proper number of cogs.

Mr. Ro-
gers's en-
gine.

The engines for parting combs, in all their modifications, have this advantage, of cutting two sets of teeth out of the same quantity of material as, with the common saw, is sufficient only for one set.

But every scale of tortoise-shell is wedge-shaped at the margin, and, therefore, it is only to the thick pieces

Manufac-
tures.

cut out of the middle part of the scale that this new invention can readily apply, for the wedge-shaped margin is not thick enough for the back of the comb. But on the whole, the advantage as regards tortoise-shell is very great, for the prime cost of rough shell of fine quality is four guineas per pound, a price greater than that of silver.

In many cases, however, the thin edge of a piece of tortoise-shell may be strengthened by soldering it to a thicker or larger piece for a back. This is done by heating the shell, and pressing it at the same time; but much care is required lest the shell be overheated, in which case the lamellar texture is destroyed, and the substance becomes as brittle as glass. In Germany and in France many combs are made, the ornamental part of which is stamped by strong pressure in hot steel dies, and two or more pieces of tortoise-shell are united in the same manner; but the colour of the shell so treated is injured, besides being rendered very brittle.

The best English makers, after smoothing and rasping the two surfaces that are intended to be united, place them between two thin boards, and insert the whole in the chops of a screw press. The press is put for some hours into boiling water, and is tightened from time to time; and thus, by allowing a sufficient time, perfect junction is obtained at a heat so low as not to injure either the colour or texture. We are indebted for the above sketch, and to the following description of a very ingenious engine for this purpose by Mr. Rogers, to the *Transactions of the Society of Arts*, vol. xlvii.

Mr. Rogers's engine, as represented in plate xxiii. fig. 1, shows two combs cut of one piece of shell before they are pulled away from each other. The shell is held on a movable bed, which is caused to move the distance of one tooth each time; two chisels are used together, so that one complete tooth is cut at each move; the chisels or cutters are fixed together, as shown in fig. 2 and 3, with four pins, and filling pieces are placed between, the thickness and taper of which are such as correctly to determine the form of the teeth. From the lower filling piece (which is shown separate in fig. 4) a sharp point descends so as to be level with the edges of the cutter; it cuts the point of the tooth away from the opposite comb; but as this double chisel cuts the tooth of one comb and the space of the opposite one, their wider ends are curved out as at *a a*, fig. 5; by this the advancing side cuts half through the point of the next tooth, and at the second move the following curve cuts through the other half, and leaves that tooth detached. Fig. 6 shows the clamp in which the cutters *a a* are held by the screw and nuts *b b*; and as these cutters have to move up and down correctly in the same place, the clamp is firmly fixed (at the right place) by its binding screw *a* on the bar *c c* of the engine; *e e*, fig. 7, are two adjusting screws, by which the chisel edges are placed correctly parallel with the bed *f f*, on which the shell is laid for cutting; *g* is the fulcrum on which the bar *c c* moves; it is a well-fitted joint, moving without shake, and placed level with the bed *f*; *h* is another joint placed firmly clamped, by its screw *i*, to the front end of the bar *c*; and as here the power is to be applied to pull the cutter *a a* down to the work, these two joints, *g* and *h*, are placed in a line level with the cutting edges on the chisels *a a*; they are both, therefore, at the moment of the cutting, level with the bed *f*; and

this is evidently the best arrangement, for by it the chisels have then no lateral motion and no tendency to tilt aside; nevertheless, to overrule all bias that might occur from unequal sharpness, or from any inequality in the substance that is to be cut, an upright loop or standard, *p*, is firmly secured to the engine; through this loop the bar *c c* passes, and can move up and down in it without any side-shake; this, therefore, guides the bar *c*, and further secures the uprightness and steadiness of the cutter. A link in two halves, and screwed together in the middle for the convenience of putting on, connects the joint *h* with the crank *j*, whose axis extends past *l*, and is supported in three standards *m*, *n*, and *o*; these standards are, for the purpose of adjustment, screwed to the projecting loops *p p p*, which, with the arm *g*, are cast in one piece with the lower bed *g*, so that the chisels are held and pulled with the greatest firmness to the cut. On the further end of the cranked axis *l* is placed a wheel *r*, with only a few teeth left on it at one side; these are so placed as only to engage the wheel *s*, when the crank *j* is up, and has lifted the cutters *a a* from the work; the wheel *s* is fixed on a screw *t*, fig. 8, which moves the bed *f f* precisely like the usual slide-rest; *u* is the standard in whose collar the screw *t* is held, and *v* the screw hole through which it passes; this is united to the dove-tailed slide *w*, on which the bed *f* is mounted; this slide is perforated to make room for the screw *t*. By turning the winch *x* the crank *j* pulls down the cutter *a a* on the tortoise-shell *y*, and cuts one tooth; the crank then lifts up the cutters, and at the same time the few teeth of the wheel *r* engage and carry with it the wheel *s*, and thereby advance the screw *t* a given proportion; the wheel *r* then quits its hold of *s* and the crank, and again brings down the cutters to form a second tooth, and so on till the whole number of teeth are cut; this done, another piece of shell is laid on the bed, and it is cut during the return of the bed by merely turning the winch *x* the contrary way, so that no time is lost.

Having now described the motion of the cutters, and the motion of the shell past them, it is necessary to explain the means of holding the horn or shell to the bed. This apparatus was purposely omitted in fig. 7, and fig. 9, 10 are added to show it: *f f* is the bed, at one side of which an adjustable plate, *z z*, is screwed for the purpose of guiding or securing the shell, to be quickly placed central and parallel; to one end of the bed is joined the double fork *l l*, and at the other end is a similar double fork *2 2*, but quite loose; *3 3* are two slender steel springs or bars; they are bent at each end like hooks, by which they are attached by screws and nuts to the joined forks *l l*, at one end, and to the loose forks *2 2* at the other; these forks keep the two bars parallel, and by them they may be adjusted to any suitable distance apart, which should be as near to the cutters *a a* as may be without touching them. These springing bars being thus joined to the bed *l l*, may be lifted by the other end to place the tortoise-shell under them; then, to keep the end *2 2* down, a wide tooth *4* projects from the middle of the forks *2 2*: it snaps past the flutes of a pendent catch *5*, by which it is retained, and thereby the springs *3 3* are held with any required tightness on the tortoise-shell *y*. The catch *5* is joined at the top to a stud *6*, and is pressed outwards against the tooth *4* by a small spring as shown in fig. 10. Again, it is requisite that the springs *3 3* should always go down

Machinery.

Manufactures.

correctly in the same place, that is, parallel with the bed *f*, otherwise the cutters might come against them and be damaged; therefore, two thin cheeks, 7 7, are attached to the stud 6, between which the wide tooth 4 passes, and is thereby always kept central, and thus prevents any lateral motion of the bars 3 3; when the springs 3 3 are to be lifted up, the catch 5 is pressed from the tooth 4 by a lever 8. The bed *f* is hollow underneath, as shown at 9, in fig. 7 and 10, for the purpose of receiving a heater during the time of cutting, as warmth renders horn or shell soft.

To set the engine for cutting finer or coarser teeth, the wheel *r* is changed for another with fewer or more teeth, and the filling pieces between the cutters are changed for others whose thickness answers to the required tooth; these, when once made, may be marked with the same number as the wheel *r*, to which they correspond. The inside faces of the chisels or cutters *a a* are kept flat and perpendicular, so that the tooth never sticks between them, and the taper for sharpening them is all on the outside. By the simple action of this engine, combs may be cut as fast as the workman can attend to them.

It is requisite, for the convenience of the workman, to cause the bar *c* either to rise up of itself or to keep up when put so; for this purpose it is but to fix the winch handle *x*, as in fig. 8, opposite to the crank *j*, and make it heavy enough always to descend and thereby lift the bar *c*; or a spring may be fixed to an arm *g*, to act against the under side of the bar *c*, with sufficient force to raise it up, or at least to hold it up. Fig. 1 to 6 are half the size; fig. 7, 9, and 10 are one-quarter; and fig. 8 is one-eighth; in this figure are shown three ears, 10, 10, 10; they project from the bottom plate *q* of the engine, and serve to screw it to any suitable bench.

(324.) *Dividing engine*.—As Astronomy has advanced to its present state of perfection, a corresponding degree of accuracy has been rendered necessary in the divisions of astronomical instruments, particularly in the arcs of our large mural and zenith sectors; so also in all quadrants, sectants, &c. used for nautical and astronomical purposes: and many of our instrument-makers have obtained great distinction for the ingenuity they have displayed in this particular branch of their Art. One of the most recent and perhaps the most simple of these engines, is the invention of Mr. Alexander Ross, a highly ingenious instrument-maker of Clerkenwell. This engine was presented to the Society of Arts in 1830, and was so highly approved of by that Body for its accuracy and ingenuity, that its author was rewarded by a presentation of their gold medal and a sum of fifty guineas. An account of the instrument is given in the *Transactions of the Society* for 1831, and to that volume we are indebted for the following description and drawing.

Historical sketch of the art of dividing engines.

Historical sketch of the art of dividing engines.—The first method which we have any correct account of is that by beam compasses; these were employed by Graham, Sisson, and Bird. Graham and Sisson obtained the chord of the arc of sixty degrees from the radius, and completed the number of divisions on the quadrant by bi, tri, and quinquesection. Bird computed the chords of certain arcs, and then completed the number of divisions by continual bisection.

Hook and Roemer practised other methods widely differing from the above and from each other. Hook's method consists in racking the quadrant with an endless

screw. Several trials of this were made at the Greenwich Observatory, but the method was found defective, and was soon abandoned. The method of Roemer was, stepping a fixed distance throughout the whole of his arc, the distance being so proportioned to the radius of the arc, that it was very nearly equal to one of the smaller divisions required; the total length of the arc in this case being disregarded, as any number of divisions were converted into degrees and minutes by a table calculated for the purpose. This method has defects which render it useless, because any error arising from the inclination of the dotted points or the porosity of the metal, is chargeable upon the whole arc, so that no dependence could be placed on the result; for his table supposes the whole arc to be truly divided.

About the time of Bird, the Duc de Chaulnes published a method of dividing by micrometer microscopes and several temporary pieces of brass having divisions upon them. Two microscopes, having cross wires in the foci of their eye-glasses, were fixed to a frame and considered as the points of a pair of beam compasses; these were extended to a diameter of the circle, and two of the temporary pieces of brass were attached to the circle by means of wax underneath the microscopes, so that the divisions bisected the crosses in them; then the circle was moved half round, and, if required, the position of the micrometers and pieces of brass were changed, and the operation repeated until they were diametrically opposite. A cutting point was then placed over one division, and a fixed microscope over the other, so that when any division was brought to bisect the cross in the microscope, the cutting point made one diametrically opposite. By the process of trial and adjustment with bisections and trisections, the circle was divided into spaces of 10° ; then by obtaining the arc of 9° by trial in the arc of 180° , the circle can be divided into spaces of 1° , and by similar means into smaller spaces if required.

Ramsden's method of dividing, consists in the use of the beam compasses, as employed by Bird, and the method of the Duc de Chaulnes combined. The circle is first divided by the beam compasses and the position of the dots accurately ascertained by means of microscopes, and corrected accordingly, by pressing the dots with the point backwards or forwards by the hand. This method is capable of a great degree of accuracy, but is tedious in the extreme.

The next great improvement was effected, and is described in the *Phil. Trans.* for 1809, by Mr. E. Troughton, in whose hands the Art has arrived at a high degree of exactness; but there are various difficulties in the application and construction of the apparatus, which it has been the object of the method now to be described to avoid by adopting principles perfectly independent of mechanical action, and governed only by vision, aided by the most powerful optical means. The roller used by Mr. Troughton is wholly rejected, and the apparatus employed is so constructed, that the character of the circle to be divided, whether slightly porous or defective, does not affect the accuracy of the operation. The method of cutting the original divisions is simple and rapid, and in number they scarcely exceed one-third of those employed by Mr. Troughton; thus reducing the labour of observation and computation, while a great practical convenience is gained by making each original division a division of the circle. The construction of the apparatus is firm, and its motion

Machinery.

Manufac-
tures.

Description
of Ros's
apparatus,
Pl. xxiv.
Fig. 3 and 4.

free from elasticity and friction; and when once adjusted, the accuracy of the divisions depends entirely upon the permanence of certain parts, which are so secured as to prevent the possibility of derangement. From the time of cutting the original divisions to the completion of the operation, the circle is free from any attachments of dividing apparatus, and is only viewed through the microscope, so that the ultimate dependence is upon vision.

(325.) The required apparatus consists of the following parts. A small circle, 10 or 12 inches diameter, divided into spaces of $3^{\circ} 45'$, or 96 parts, by the usual dividing engine, or by any ordinary means; two micrometer microscopes represented in pl. xxiv. at *a b*, fig. 3 and 4, which are top and side views; an arc *c c* of the length of $3^{\circ} 45'$ of the circle to be divided; a cutting frame *d e*; and a frame *f f g g* to support the apparatus. The frame *f g* consists of a bottom and top plate connected by two strong pillars; one of them is represented at *h*, the front one being moved to show the other parts. In the bottom plate are screwed the nuts *i i*, fig. 3, which form adjustable feet for the frame; these nuts are perforated, and the screws *j j* pass through and fasten the whole securely, after being levelled by the nut *i* and level *l*. The upper plate is secured to the pillars *h* by two screws and collets *k m*, moving on *k* as a centre, and adjustable at *m* by the pushing screw *n*, for the purpose of setting the cutting point *o* (which is attached to the upper plate *f*) to cut a radiating division on the circle to be divided; an arc and index at *p*, fig. 4, indicate the inclination given. To the upper plate is likewise attached the hollow centre *g*, fig. 3; in this works a male centre, the flanch of which is seen at *r*, fig. 3; this supports the bar *s s*, which carries the microscope *a b* and level *l*. The microscopes are secured to this bar by two pulling and two pushing screws *t t*, *t t* passing through a flanch *v*, and acting in and on the bar *s*. The microscopes are secured to the flanch by fitting into strong tubes *u u*, fig. 3, which are soldered into the flanches *v v*, and when adjusted to distinct vision, can be fixed in that position by the clamping rings *w w*. The handle *x x* for the cutting frame is attached to the perpendicular slide *d*, having a double joint at the point where it is fixed; in order to prevent any unequal pressure from producing a lateral motion of the cutting point, the other end is connected to the upright dovetail slide 3, 4, which forms part of the apparatus for moving the cutting point, and will be found fully described in the account of the dividing engine. The openings are for the purpose of permitting the arc to be viewed through the microscope during its passage over it, and to pass the centre *q*, when continued to the cutting frame.

The first part of the process is to make ninety-six divisions at a convenient part of the circle, according to the arrangement of the cutting point and microscope *a*, upon silver dots inlaid for that purpose; and it may be here necessary to remark, that the part of the circle upon which the divisions are to be made must be turned with the most scrupulous exactness; and when the greatest degree of accuracy is required, and microscopes of high power are employed, it will be necessary to turn the circle in its ultimate position, and when the whole is of the same temperature. To obtain the divisions, let the instrument be placed upon its stand, or on a temporary one, composed of the same metal as the circle, in its ultimate position, and fix the small circle upon and concentric with the one to be divided. Fix one of the

microscopes over the divisions on the small circle, and fix the cutting point over the part of the circle intended for the original divisions. Having determined the zero point of the circle, place the cutting point and microscope in such positions that the first original division shall be the half of $3^{\circ} 45'$ (by ordinary estimation) from it. The apparatus is then ready, and the whole of the ninety-six divisions may be cut by successively bringing a division on the small circle to bisect the cross in the microscope.

This small circle and microscope may now be removed, and the second part of the process performed; (which is the same as Mr. Troughton's, except that the first step is a trisection instead of a bisection;) but as the process can be carried on by bisection to $11^{\circ} 15'$, it has been performed both ways, the corresponding results being a severe test of the accuracy with which this most important part of the operation is performed. Likewise testing the mechanical action of the instrument, the errors being ascertained by bisection, precisely on Mr. Troughton's plan, we cannot do better than quote his description.

(326.) "The circle remaining in its ultimate position, the two microscopes must be firmly fixed to the stand of the instrument on opposite sides, and the wires brought to be bisected by the first or zero division, and the one which should be 180° distant. Now, the microscopes remaining fixed, turn the circle half round, or until the first microscope coincides with the opposite division; and if the other microscope be exactly at the other division, it is obvious that the divisions are 180° apart, or in the true diameter of the circle; and if they disagree, it is obvious that half the quantity by which they disagree, as measured by the divisions of the micrometer head, is the error of the opposite division; for the quantity measured is that by which the greater portion of the circle exceeds the less. It is convenient to note these errors + or -, as the divisions are found too forward or backward, according to the numbering of the degrees; and for the purpose of distinguishing the + or - errors, the heads are numbered backwards and forwards. One of the microscopes remaining as before, remove the other to a position at right angles, and considering for the present both the former divisions to be in their true places, examine the others by them, *i. e.* as before, try by the micrometer how many divisions of the head the greater half of the semicircle exceeds the less, and note half the quantity + or - as before; and do the same for the other semicircle. One of the microscopes must now be set at an angle of 45° with the other, and the half difference of the two parts of each of the four quadrants registered with their respective signs. The microscopes must now be placed at the distance of $22^{\circ} 30'$, and the half differences of the parts of all the arcs of 45° measured and noted as before, thus descending by bisections to $11^{\circ} 15'$. During the whole of the time that the examination is made, all the divisions, excepting the one under examination, are for the present supposed to be in their true places; and the only thing in this important part of the business, from first to last, is to ascertain, in divisions of the micrometer head, how much one of the parts of the interval under examination exceeds the other, and carefully to tabulate the half of their difference.

"The foregoing examination furnishes materials for the construction of the Table of half differences or apparent errors. The first line of this Table, with a distance of 180° , is the real error of 180° . The second

Machinery.

Method of
testing the
divisions, as
practised by
Troughton

Manufactures.

Pl. xxv.
xxvi.

From a series of observations made upon several instruments, to determine the errors of the ordinary dividing engine, it occurred that in large arcs the errors varied from 5" to 17", but on the examination of some smaller arcs, the mean error was about 4"; and as the linear value of this angular error will be directly proportional to the radius, it follows that if an arc, as in plate xxv. fig. 12, is divided into angles at a short radius r , so that when placed at a longer radius R , a point moving round the centre c , and passing over the divisions on that arc placed at R , makes equal angles $a a$ when in coincidence with each division, the angular error in the

equality of those spaces will only amount to $\frac{r}{R} e$, e being

the angular error of the part of the dividing engine used in cutting the divisions at the short radius; and if this operation is successfully repeated by attaching the arc to the engine plate, and fixing a microscope over the divisions instead of using the screw, as in the first instance, the utmost limit of accuracy that the motions of the cutting frame and vision, assisted by the most powerful means, is capable of, can be obtained. In applying this principle to obtain the divisions on the arc, let A , plate xxvi. fig. 11, be the centre of the circle to be divided, $A M$ the shorter radius of the original divisions, M the micrometer from which the apparent errors were registered. This microscope is attached to an arm $b m$, and moves on a centre c , (the same as marked $s s$ and q in fig. 1, pl. xxiv.) and m is the other microscope observing the arc.

Let $M b$ be the half of an original space, then c will be the angle when the microscope M is observing the original divisions in its extreme position, and its opposite angle being equal, it will also be the extreme angle on the arc, to obtain which there is the triangle $A b c$ with the angle A given, being the half of an original space $= 1^\circ 52' 30''$, and $b c$ may be ascertained according to convenience, or the determined ratio of the radii, and $A c = b c + A M$; then $b c : \sin A :: A c : \sin b$,

$$\therefore \sin b = \frac{\sin A \cdot A c}{b c} \text{ and } c = 180^\circ - (A + b). \text{ And}$$

this is the form for computing all the angles on the arc; for as the instrument is divided into spaces of 5', the angle at A is successively the preceding angle $- 5'$, and the sides $A c$ and $b c$ are constant.

It will now be seen, that the length of the original divisions must be equal to the versed sine of the angle c to the radius $b c$, or $c M$, and that they should be truly radiating. It will also be observed, that as the error of the division is taken at its shorter radius, it will be greater as the radius is increased, and likewise that, at the time of observing, the micrometer was a tangent to the circle; but when the microscope is observing the extreme division on the arc, and the original division is brought in the field of the other microscope, it is observing a different part to that used in obtaining the error, and the micrometer is not a tangent to the circle. These circumstances show the necessity of cutting the original divisions in their true places before dividing the whole circle; for, if the erroneous divisions were used, as in Mr. Troughton's plan, it would be necessary to apply a correction at several stages of the original space, according to the extent of the real error and the angle c , which would be rather a complex operation and introduce the liability of mistake.

The next step, therefore, is to cut the original divisions

in their true places, which is performed by using the cutting frame the same as in cutting them originally and adjusting the point to cut a radiating line by making long, opposite divisions on thin temporary pieces of brass, and to observe the error at each end of one of them, and incline the point by the screw n , fig. 4, until the errors are alike, or until there is no error, when one of the microscopes is moved to each end of the division. Then fix the cutting frame at the right convenient distance, and also fix the micrometer, which was used in obtaining the apparent errors, to the upper plate of the frame of the apparatus by a temporary arm, and previously to cutting each division, place the micrometer head at the real error of the division under the microscope, $+$ or $-$, as extracted from the computations. This operation being completed, it gives additional satisfaction to examine the divisions again, and if correct, the whole divisions may be cut on the circle.

The apparatus complete, as represented at fig. 1 and 2, is used in this operation, and is to be placed on the stand in such a position, that the distance between the centres $A c$ shall be as nearly equal to that used in the computations as ordinary means will command. The cross is now to be taken out of the microscope a , and a thin plate of metal put in its place, with a small hole perforated, such that the image of the divisions will occupy about three-quarters of its diameter; then to bring the various parts into adjustment, first make the surface of the circle perfectly level, and the centre of the apparatus perpendicular by the level l attached to the bar s ; this will preserve the distinctness during the passage of the microscope a over the circle, while the microscope b is passing over the arc. The next adjustment is to make the centre of the circle the centre q , and the middle of the arc c in a line, and that the microscope b , in moving between the extreme divisions of the arc, shall move the microscope a accurately over an original space. To effect this, it is necessary to have a boundary line described to the original divisions, which should be made at the time the circle is turned, with a fixed point, so that it may be perfectly concentric, and the original division should be made to intersect this circle. Half way between any of the original divisions, there should be a division, which is to be made at the time of cutting the original divisions, and the error of it obtained at the time the original divisions were verified; then, having placed the microscope b over the divisions on the arc, (which should have its middle division cut at the time of cutting the other divisions,) bring the hole in the microscope a over an original division at the intersection of the circular line. The circle remaining stationary, move the microscope to the next original division, and observe if the intersection of the circle and original divisions are in the hole in the microscope; if not, move the circle of the microscope, and repeat the operation until the intersections pass the centre of the hole in the microscope in its course over the circle. The circle remaining in this position, place the microscope a over the division between the original divisions, allowing for its error; then adjust the microscope b for its cross, to be bisected by the middle division on the arc. The microscope b is now to be placed at an extreme division on the arc, and an original division brought into the other microscope; then move the bar s until the other extreme division of the arc bisects the cross, and observe if the original division bisects the hole in the other microscope; if not, the

Manufactures.

microscope *a* must be moved to or from the centre of the circle, as the microscope is found to measure too small or too great a space; for, the original divisions being radiating, the nearer the microscope is moved to the centre of the circle, the smaller will be the linear value of an original space, and *vice versa*. These adjustments must be carefully performed, and verified at intervals, until the angle moved through by the bar *s*, governed by the arc *c*, coincides accurately in the microscope *a* with an original space, and the middle divisions of the arc and original divisions agree with the cross and hole in the microscopes at the same time.

Process of cutting the divisions.

(328.) The apparatus is now ready to cut divisions: to perform which bring the micrometer head of the microscope *a* to zero; and let the cross in the microscope *b* be bisected by an extreme division on the arc *c*; then bring the zero original division to bisect the hole in *a*. It will be recollected, that the zero original division was placed half an original space from the real zero; and when the apparatus is placed as above directed, the cutting point will be found half an original space from the original division, so that the zero division of the circle will be in its right position. The microscopes and circle being in this position, let a division be cut, then move the bar *s* by the pushing screw *y*, until the next division on the arc bisects the cross; then move the circle by its tangent screw until the original division bisects the hole, and cut again. Proceed in this manner through the whole original space; then leaving the circle in the position in which the last division was cut, move the bar back to the first division on the arc again, and observe that the next original division now bisects the hole in *a*; then proceed as before to cut the whole of the divisions in that space, and the same for the whole of the circle. It may be observed, that a test of the permanence of the adjustments of the apparatus is formed at every space by the original divisions bisecting the hole in *a*, when the microscope *b* is moved back to the beginning of the arc.

The long handle *x*, fig. 3 and 4, which moves the cutting point, prevents any partial expansion in the apparatus; and for this purpose the whole may be enclosed and viewed through a plate of glass at the top. A narrow slit will be sufficient for the handle to pass through; the handle *x* serving the same purpose as the connecting bar 25 in the engine, plate xxvi. fig. 1, and is joined like that to the vertical slide 34 of the moving apparatus. But there is an arm 2 attached to *x* which projects under the frame *e* to lift the cutter off the work, when the bar *x* lowers; therefore the action of the lever 22, plate xxv. fig. 1, will be reversed when the point is cutting the divisions, by which arrangement the bar *x* will be raised while making the cut, and lowered to return.

The best light is considered to be an Argand lamp, placed outside the apartment in which the operation is performed, and refracted or reflected through a hole to the divisions. This will likewise give sufficient light in the room to move the adjusting screws and cut the divisions. These arrangements prevent the possibility of partial expansion from the heat of the light, and enclosing the apparatus, prevents the same from the proximity of the body, the breath, or the heat of the hand; and as this is the only thing that can affect the accuracy of the operation in this method of dividing, it must be guarded against in every direction, which the construction of the apparatus greatly facilitates. It

may here be noticed, that the effect of partial expansion must be observed in the second part of the process, when the apparent error of the large arcs is taken. For this purpose there should be several thermometers applied at various parts of the circle; and before observing, it should be ascertained that they all indicate the same temperature. This is of the greatest importance, as the errors obtained by trisection, if this is not scrupulously attended to, will not agree with those obtained by bisection; but in the smaller arcs it is only necessary that they individually should be at the same temperature. The microscopes used have the focus of the object glass about ten times the distance of the plane of the divisions from it, and the screw has 100 threads in an inch; this is moved by a micrometer head having 100 divisions, so that by this arrangement the value of each division is $\frac{1}{10000}$ of an inch. The cross wires are placed at the angle 20° , and, with a little experience and fine optical powers, the bisection of the cross by a division may be observed within this value.

The method of filling up an original space by copying an accurately divided arc by microscopic means, may be applied in various ways. First by a frame rolling on the arc of the circle carrying the microscopes, and the cutting frame and arc to be copied on the stand. The microscopes may also be attached to a bar having a Y at one end bearing on a cylinder on the centre of the circle; but these modes are objectionable, as they encumber the circle to be divided.

(329.) This method of dividing can with facility be applied to linear instruments. For this purpose a plane of brass, or cast iron, about eight inches wide, and of the requisite length, having its edges perfectly straight, is necessary to support the apparatus, which in this case is to move along the bearer or plane, being guided in its motion by studs rubbing against the edge and kept in contact by a spring and rollers acting on the other edge. The series forming the original divisions (supposing a scale of inches

Linear dividing.

and parts) is $\frac{36}{3} = 12$ in. $\frac{12}{2} = 6$ in. $\frac{6}{2} = 3$ in., the errors

of which are to be taken and computed as directed for circular dividing; and these can be verified by bisection

down to 4.5: for $\frac{36}{2} = 18$ in. $\frac{18}{2} = 9$ in. $\frac{9}{2} = 4.5$ in. The

space of 1.5 being filled up with equal and parallel divisions, the angles on the arc can be obtained by making the difference of the tangents to the radius *c M*, plate xxv. fig. 11, equal; for suppose the scale to be divided into tenths of an inch, then the first tangent from the middle of

the arc $= \frac{1.5}{2}$ in. $= .75$ in. and the tabulated natural

tangent of the extreme division on the arc will $= \frac{.75}{c M}$,

and the tabulated natural tangent of the other angles will be successively the preceding linear value on the

scale $\frac{.1}{c M}$. The original divisions are to be cut in their

true places, precisely as described in circular dividing; and in cutting the whole of the divisions, the only difference is, that the apparatus is movable instead of the instrument to be divided.

By this system accurately divided scales of any description can be obtained; as it appears peculiarly

Manufac-
tures.

adapted for those of zenith sectors, the application of which must be sufficiently obvious.

Description of the Dividing Engine.

Description
of the en-
gine at
large.

(330.) Since the construction of the endless screw-dividing engine by Ramsden, there has been but one improvement made of any consequence, viz. that of Mr. Allan, which appears well calculated to correct errors arising from the gradual increase or decrease of the size of the teeth in the circle; but where the asperities are to be removed by such an obtuse cutting angle as that presented by a serrated cylindrical screw, the pressure required is too great to be compatible with those delicate operations which are necessary to obtain the accuracy which such an engine ought to possess. There are other difficulties arising from the heterogeneous nature of even the best steel that can be obtained for forming the screw, likewise the porosity and want of homogeneity in the cast materials forming the circle. These considerations, which were deduced from a practical acquaintance with the subject, led Mr. Ross to a mechanical modification of the previously described primitive method of dividing, of which the engine now to be described is the result.

The principal mechanical action, or that which regulates the motion of the circular plate, is the reverse of the endless screw, which acts by driving. In this engine a rotary motion is applied by an independent apparatus, and the circle is stopped at its precise angular position by the contact of plane and spherical surfaces of hardened steel, their truth being ascertained, by preliminary experiments, to be far within the limit of admissible error.

The engine is represented at fig. 1, plate xxv. and xxvi. The former is a top view of the engine, and the latter a sectional view, 1 1 is a frame of cast iron, on which the engine is mounted; 2 2 the hollow centre screwed to the frame by the flanch 3 3; the axis consists of two similar cones 2 2, which are screwed to the circular plate *a a a a* by its flanch. Around the circle are screwed 48 cocks, *b b*, &c., having capstan-headed screws *c c* (shown half the real size in fig. 2 and 3, plate xxv.) passing through them parallel to the plane of and tangent to the circle. The ends of the screws are hardened and ground flat and square to the axis; this is effected by screwing them into a piece of brass about one inch and a half in diameter, whose thickness is rather less than the length of the screw. This must previously have its surface turned flat upon a true screw arbor, then the projecting end of the screw is to be ground off upon a flat metal surface until it is level with the turned surface of the brass. These screws may be fixed in any position by the tightening screws *d*. The weight 4 on the lever 5 supports so much of the weight of the circle as to let it move pleasantly. At one end of the stand of the engine is a sliding plate which carries the worm *e e*; it is movable by the screw 7, for placing the worm in or out of gear with the cocks on the circle. The plate is brought into its precise position by three steady pins 9 9, and secured by four binding screws 10 10; two of them, with one steady pin, go in underneath, and are not shown. The distance between the shoulders of the screw 7 being greater than the thickness of the standard 8, is for the purpose of preventing strain upon the steady pins. The worm *e e*, or one single revolution of a square-threaded screw moving on a horizontal axis, having the distance between its threads equal to the distance of the ends of the tangent

screws *c c*, &c. on the circle, is pierced parallel to its axis with ninety holes to receive capstan-headed screws *f*, fig. 2, plate xxv. with spherical ends; these have also tightening screws *g*. The pivots of the axis are turned with a screw tool so as to have rings on them, and the bearings have corresponding rings within; this prevents any shaking; one of the pivots is seen in fig. 6. On the outer rim of the circle a groove *h*, fig. 3, is turned, in which a slight catgut *i i*, fig. 1, passes round, moving over pulleys *j j*, and then under the weighed pulleys *k* and *l* at each side; the weight *k* being superior, always brings the screws on the circle in contact with those in the worm *e*. The gut *i* rises from the weight *k* to the clamp *m*, where it is bound fast; it then passes above the engine on a notch *n*, and then down to the pulley *b* in an endless band, of such a length that when one weight is up the other is down. When the weight *k* is down, the clamp *m* is to be loosened and *k* rises, this lets the weight *b* run down the clamp; *m* is then to be tightened, and the whole is ready for action again. The portion which passes over the engine is broken away, that it may not interfere with the view.

The four pillars 11 11 support the triangular bar 12 12, on which slides a saddle 13, to which is appended the cutting apparatus, of which fig. 6 is a front view, and fig. 7 is a side view; 14 14 is a sliding plate to adjust the height of the swing frame 15 16; the part 17, in which the cutting point is fixed, may be secured at any inclination by the screws 18 18. The pedestal 19 supports the moving apparatus; fig. 8 shows it partly in section, and fig. 7 is a front view; 20 20 is a dovetail sliding bar, with a standard 21 rising from the middle; 22 is a forked lever, the prongs of which embrace the standard to give an alternate motion to it and the bar 20; the diameter of the standard is about two-thirds of the opening in the forked lever. Fig. 8 shows the frame in which the bar 20 slides with a stud 23, on which the lever 22 moves. To the sliding bar 20, plate xxvi., is joined a vertical sliding frame 24, to the sliding bar of which is joined the adjusting bar 25, which connects this moving apparatus to the swing frame 15; the vertical sliding frame 24 is also joined to the sliding bar 20, and connected to the standard 21 by an adjusting bar 26, in order to give that inclination to the sliding frame 24 which prevents motion in the swing frame and cutting point during the rise or fall of the connecting bar 25. To the swing frame 15 is screwed a double joint 27, shown fig. 7; in this one end of the connecting bar 25 moves concentric with the axis of the cutting frame 16, but quite free from it. Upon the bar 25 is mounted a frame 28, fig. 1, 7, and 9, in which a bar moves by the adjusting screw 29; at the bottom of this bar is a square opened cross, to which another small bar 30 is screwed, and from the frame 16 projects a cylinder 31, fig. 6, which passes through the opening and rests upon the bar 30, so that when the bar 25 rises it lifts the cutter 32; fig. 9 is a balance weight. A lever 33 is joined on the sliding bar 20, shown in fig. 8 and 10; the long arm passes under the upright sliding bar 34 in the frame 24, and the short arm terminates in an inclined plane, which rises in the space between the fork and the standard 21; then during the motion of the fork through the space which is not occupied by the diameter of the standard, it presses the short end of the lever down, and by the alternate motion permits it to rise before the inner sides of the fork act upon the standard 21.

Machinery.

Manufactures.

Now, to exemplify the method of using this apparatus, let the handle 22 be in the dotted position nearest the engine, plate xxv., then the short end of the lever 33 will be depressed and the slide 34 elevated, and with it the bar 25 and frame 28, and let the cutting point be lifted off the work to be divided; then move the handle 22 gently from the engine; this will permit the short end of the lever to rise between the fork and the standard, and the long end will be depressed, and with it the slide 34, the connecting bar 25, and the frame 28, until it has left the cutting point resting on the work; the inside of the fork will now be nearly in contact with the standard; move the handle further, and this will press forward the slide 20, the connecting bar 25, and the swing frame 15, which will draw the swing 16 and cutting point along with it, and make a division; then reverse the motion of the handle, and the fork will press the short end of the lever down; this will raise the slide 34, and with it the cutting point, from the work; the other inside of the fork will now be nearly in contact with the standard; move the handle further, and the slide 20, with the connecting bars and cutting point, will be brought back ready to cut another division. The lengths of the divisions are regulated by a cross piece 36, fig. 8 and 10, on the top of the standard 21, coming in contact with the end of the screw 35, and the edge of the circular steel plate 37. The short divisions are limited between the ends of the screw 35, and the edge of the steel plate, and the longer divisions are given by notches in the steel plate, which let the stop 36 move so much further; and these notches are presented in the proper order by a ratchet wheel 38 (which moves on the same centre pin as the steel plate shown in fig. 8) and a click 40, which is connected to the forked lever 22 by an adjustable arm and stage 39, supported by three pillars shown separately in fig. 8; this click is kept in contact with the teeth of the ratchet wheel by a slight spring, so that the same motion which operates in cutting the divisions constantly regulates the lengths of them. When cutting from the centre, the lever represented, fig. 12, is to be used instead of that previously described; and when the long and short divisions are on the outer circumferences, the steel plate 37 and screw 35 change places. By this method of cutting the divisions the body may be at some distance from the cutting point and circle, which prevents the effects of partial expansion in the dividing apparatus and instrument to be divided, which must necessarily occur in the course of an operation in the ordinary method, from respiration and the heat of the hand. It also cuts the divisions uniformly straight and equable, likewise obviates the necessity of circumscribing the divisions with a deep coarse line, thereby considerably reducing the liability of breaking the point, which is of great importance in the use of the diamond.

The lever, to which is attached the handle *w*, regulates the motion of the worm and circle; this lever passes through the pedestal, and moves upon a centre pin within it; to the short end of the lever *z* is joined the connecting bar *x x*; near *z* is an adjusting screw, by which the motion of the lever and bar is limited; the other end of the bar *x x* has a double joint, by which it is connected to the arm *y*, fig. 5 and 6; the opposite arm 44 carries a spring click: these arms move in a hollow axis concentric with the worm, but independent of it; a section of this is shown in fig. 6. The axis of the arms *y*, 44 is supported by the standard

47, which is screwed to the plate 66, which carries the Machinery worm, the spring click moves the ratchet wheel 45 attached to the worm, and is stopped at this end of the bar by the arm *y* abutting against the stud 46, fig. 5, and is limited in its motion the other way by its screw at *z* stopping the motion of the lever. A spring 41, faced with leather, presses against the catgut *i* and rim of the circle; this prevents the motion of the circle, until the spring is removed out of contact by the pressure of the screw 42. Now let the handle *w* be in the position represented in plate xxv., then move the handle from the engine; this will move the bar *x x* the contrary way, and will move the arm *y* from the centre until it stops against the stud 46; this motion will have brought the arm 44 and spring click towards the centre, and have moved the ratchet wheel and worm round, and, consequently, moved the screw in the worm out of contact with the screw in the circle; the handle *w* is now to be moved back, when the click passes over the teeth in the ratchet wheel, and the worm remains stationary; the screw 42 will then come in contact with the spring 41; now press the handle a little further, (as represented by the dotted lines,) and this will remove the spring out of contact; the weight *k* will immediately give motion to the circle, and bring it in contact with the worm. In removing the spring out of contact, the power should be gently applied, so that the circle slides round and does not drop with any violence against the screw in the worm; and when the contact of the screws is complete, the spring should be kept out of contact with the circle, then at the distance of cutting the division the circle is under no influence but the constant force of the weight *k*. The length of the screw at *z*, with several holes in the bar *x* to join the bar to the lever, afford convenience to escape over as many teeth of the ratchet wheel 45 as may be required.

In fig. 1 is an iron segment 48, supported on three arms projecting from the iron stand 11; upon this are fixed three pillars, 49, 50, 51; two of them hold micrometer microscopes, 52, 53, the other, 51, holds the screw 54, which acts against the piece, fig. 9, when it is screwed on the circle, and the worm *e e* is drawn out of gear. This is used when dividing vernier scales, these being obtained from divisions made by the engine upon the silver ring by means of the micrometer microscope.

This description has chiefly applied to the construction of the engine for transferring divisions by the mechanical action of contact; it now remains to be described how the various parts are regulated, according to the principles laid down in the primitive method of dividing.

Corresponding to each cock *b*, on the circle is inlaid a small circular disc of silver to receive original divisions. These are to be made, and the errors of them obtained, as directed in the primitive method of dividing; then the ends of the screws *c* on the circle may be adjusted to their true position, by fixing the microscope placed at zero over the original division zero; when a screw *c* on the circle is in contact with one in the worm *e*, then move the worm one revolution, and the next screw in the circle will be in contact with the same screw in the worm, and the next original division will be under the microscope; place the micrometer head at its real error, and move the screw *e* on the circle until the divisions bisect the cross in the microscope, and repeat the same operation with the whole 48 screws. The means for adjusting the screws *f* in the worm are

Manufao-
tures.

similar to those in the primitive dividing for filling up the original space; but in this case the constant sides of the triangle are different.

Let c , fig. 4, plate xxv. be the centre of the dividing engine, cb its radius, and $ba = \frac{bc}{m}$; then, as before, bd

= half an original space, and as the angles are to be $5'$, (this being the angle given by the number of screws, and affording all the variety in dividing astronomical and mathematical instruments,) the angles at c will be successively $3^\circ 45' - 5'$, $(3^\circ 45' - 5') - 5'$, &c.; then

$$(ac + bc) : (bc - ac) :: \cot \frac{c}{2} : \tan \frac{a-b}{2} = \frac{bc - ac}{ac + bc} \cot \frac{c}{2};$$

then

$$\frac{a-b}{2} + \frac{a+b}{2} = a, \text{ and } 180 - \left(\frac{a-b}{2} + \frac{a+b}{2} \right)$$

= the external angle at a . Then, for the most convenient form of computing the angles, this reduces to

$$\frac{bc - ac}{ac + bc} \cot \frac{c}{2} = \tan \frac{a-b}{2}, \text{ and } 90^\circ + \frac{c}{2} \frac{a-b}{2}$$

= the angle to be cut upon the arc, fig. 10.

It is necessary that the boundary lines on the scale should be described while revolving with the engine, and that the first and last division should intersect these lines; the dividing point should also be adjusted to cut a radiant line. This affords the method of making the two centres and the middle of the arc in a line when placed at its longer radius. For this purpose it is only necessary to make the intersection pass the centre of the hole in the microscope. The other microscope is now fixed over the original divisions, and the one over the arc must be adjusted until the space between the extreme divisions on the arc equals an original space, as directed in the primitive dividing. The screws f in the worm e are now to be adjusted until each division on the arc bisects the hole in the microscope when the screw in the worm is in contact with the one on the circle. The engine should now be worked round several times, and the adjustments repeated at intervals, until they are found to be constant and perfect. Thus, by the most delicate operations, the engine is rendered capable of moving through its angular spaces with a great degree of accuracy and certainty; for without very minute examination and adjustment the engine can be regulated within $2''$; and from observations made with delicate adjustment and minute observation, the contacts may be made to a division of the micrometer head which is one-fourth of a second.

There are two sources of error in this Machine: first, the difference of expansion in the worm and stand, the worm being of bell metal, and the stand of cast iron, then the worm expanding above $\frac{1}{100000}$ parts of its whole length for each degree of temperature, which is about one-fourth of a second, and the expansion of cast iron being about two-thirds that of bell-metal, the difference

$$\frac{1}{4} - \left(\frac{2}{3} \text{ of } \frac{1''}{4} = \frac{1''}{12} \right);$$

so that it is necessary to adjust the worm in a mean temperature, then this source of error will not affect the accuracy of the engine in any material degree when the temperature is between 35° and 70° of Fahrenheit. The

other source of error is, that the ends of the screws on the circle are not perfectly square on their axes; and as the spherical ends of the screws in the worm do not come in contact with the flat ends of those of the circle at the same point in every contact, but differ nearly as the secant of the angle, (this at the extremes is about one-thirtieth of an inch,) therefore any difference in the inclination of the ends of the screws on the circle will produce error. This error can be halved by adjusting the screws on the circle against that screw in the worm which comes in contact in the mean point; this occurs at the eleventh screw for the extreme; then by removing the microscope so that an extreme screw comes in contact with the screw on the circle, when the original division is under the microscope, the amount of this error can be obtained. In this case, in some places, it amounts to $1''$; so that if all the greatest errors occur at the same time, and all the same way, the error will be about $3''$.

The usual method of centring the instruments to be divided on the engine is very defective, for it often happens that the axis of the motion of the instrument is not truly in the centre of their permanent fittings; and this, with other causes, produces a disagreeable eccentric error in circular instruments, though really of no consequence where there are two verniers, for the angle observed is an angle within a circle, and is measured by half the sum of the intercepted arcs, therefore half the sum of the opposite reading will be the true angle; but in instruments having but one vernier, and more particularly in sextants, this produces serious error, for the eccentric error has been seen such that it might produce an error in a sextant to the extent of $3'$. This led the inventor to devise a method of centring, whereby the axis of motion of the centres of the instrument may be made in a line with the axis of motion of the centres of the dividing engine, and is thus effected. Suppose the instrument to be a sextant, then to the flanch, fig. 2 and 5, plate xxvi. of the male centre is screwed or cemented a double dovetail slide qr , fig. 2, 3, and 4, the slides at right angles, with drawing screws ss and spiral springs tt to each slide, and on the upper slide is made a dot. The instrument is laid upon the centre of the engine plate, and over the dot is fixed a microscope, fig. 11, with cross wires. The male centre o is then made to revolve, and the slides adjusted until the dot is perfectly stationary; the engine plate a is then made to revolve, and the instrument is moved by the pushing screws uu and opposite spring slides vv , fig. 5, the dot is again stationary during a revolution. Thus by the first adjustment, the dot is in the axis of motion of the centre of the instrument, and by the second the same is made in the axis of motion of the dividing engine. For other instruments there are four adjustable dots placed at a convenient distance from the centre, and these are made to pass a wire in the microscope while revolving on its own centre likewise, when on the engine. This affords a great convenience in circular instruments, and is an improvement of considerable importance in sextants.

(331.) *Engine for drilling.*—The common process of drilling with what is called the drill bow is sufficiently well understood, but for the heavier sort of iron work more powerful means must be had recourse to. These means may be supplied by cranks worked by men, or by wheels and shafts driven by water or steam. In plate xxiii. fig. 11, is represented an elevation of a powerful hand engine for this purpose. Here AB is the ground-floor, A, B , Drilling engine.

Manufac-
tures.

and C being large blocks of stone laid down to receive and support the cast iron frames; to secure these to the stones, iron pins with screws cut on them are first let into the stones and passed through holes cast in the several plates, to which they are then firmly screwed down by nuts. D E are two standards for carrying the winch or handle F, intended to be worked by three men. G is a strong double cast iron frame, intended to support the bevelled wheel which works the horizontal bevelled wheel I; through the centre of this wheel slides the drill shaft, so that it may descend freely through it, and follow its work as the drilling proceeds; in some cases this shaft is square, but it is more commonly cylindrical, with a recess to take a feather left in a cavity of the wheel's centre. In the collar L the drill shaft also passes freely, and the latter is united above with a rack, as seen in the drawing. This rack is worked by a small pinion m, by means of a wheel fixed on the same axle with it, but being on the other side of the frame, is not seen in the elevation; over this wheel passes an endless chain, which hangs down, so that a man pulling on it may raise the rack and drill shaft to any required height, at which it will be supported by means of the ratchet wheel and a spring pall, seen on this side of the frame at M.

N N is an iron stage, which may be raised to any required height and secured there by means of holes left in two standards O O, one only of which can be seen in the figure, the other being between the two sides of the principal frame, but its situation is shown by the dotted lines. P is a pit sunk in the floor of the building for the convenience of turning downwards any long arm or other part of the ironwork which may be required to be drilled by the engine, such as the iron knees of ships, and various other heavy ironwork; when, however, it is not required for use, it is covered over by flooring boards, and the engine then assumes a very simple and compact form. W is a fly wheel to give a steadiness to the motion, and is what the workmen call loaded with wood on the circumference towards where the handle is placed; that is, square holes are left in its rim, which are filled with wood; this is intended to remove a weight towards that part equal to the crank, so that the latter may be balanced by the other side of the wheel, and thereby stand in any position in which it is placed, instead of always descending to its lowest position, as it would do without this or some similar contrivance. The drill H is inserted in a socket in the bottom of the shaft, and is there secured by a bolt, and may of course be shifted and changed according to the size which the work immediately in hand may require. When the hole is very large, as for instance two or three inches, a hole of a less size is first drilled, and then a tool is used instead of a drill to enlarge it, fitted with a cutter on each side, and this cutter is changed as the work proceeds till the proper dimension is attained.

The drilling engine here described is one at present being erected in his Majesty's Dock-yard at Woolwich, constructed by Mr. Kingston, an ingenious millwright of Portsmouth. In the same establishment are two other more powerful engines for drilling which are worked by a shaft turned by the steam engine, which are in their principle of action nearly the same as the preceding, except that the principal shaft driven by the steam engine is much higher, so that the drill receives its motion entirely from above; and the rack by which it is elevated is also considerably higher, and works between the two parallel sides of a cast iron frame, but

the drill is elevated, and the pressure brought upon it when at work by an endless chain, as already described.

(332.) *Engine for cutting files.*—This is rather a desideratum in Mechanics than one in actual existence, at least in that degree of perfection which the process requires, although many very ingenious men have devoted a good deal of time and attention to the subject; amongst others, the late Mr. William Nicholson, editor of the *Scientific Journal*, so well known under his name. Another engine also for this purpose is described in the *American Philosophical Transactions*, as also in Gregory's *Treatise on Mechanics*, and in other English Works. Generally, however, it is considered that the best files are those cut by hand; and it will, therefore, be more satisfactory to the reader to be informed of the nature of the manual process, than for us to enter upon the description of a Machine which, however ingenious in itself, is not generally applicable to the purpose for which it is designed. A file which is of the same breadth and thickness throughout, may certainly be cut by either of the engines above referred to, the same degree of percussion being required for every tooth; but if the file be conical, it is obvious that a very complicated engine would be requisite, and great delicacy of operation to cut all round with the precision it may be effected by hand. A chisel also employed in this process is very liable to chip or to get otherwise out of order, which the workman immediately feels, and makes the requisite repairs; whereas with the engine such an occurrence would not be detected till the file was examined. In cutting by hand, the workman sits on a block of such a height as is found convenient, placing himself astride as on horseback; he is also, as in that case, furnished with a leathern strap, answering as stirrups, which strap, passing over each end of the file, retains it in its place by the pressure of his feet; he then, with the chisel in one hand and the hammer in the other, raises the teeth with a dexterity obtained by practice which is very astonishing. In cutting the first side of the file, it is rested on an iron anvil, but when the second side is cut, a piece of thin lead is laid on between the anvil face and file, in order not to damage the side already cut. Great care is necessary in preparing the edge of the chisel, which is in the first place hardened and tempered at a yellowish-brown heat; the edge is next ground very true, and afterwards finished on a turkois stone with oil; it is not made very sharp or fine, the bottom of the cut or tooth requiring to be rather open, to prevent the file from clogging with the substance filed; the edge is, however, required to be very smooth, in order to its slipping easily along the surface during the operation; for it is simply by the feeling that the process is conducted, and if the edge were not very smooth, it would be impossible to preserve that uniformity in the distance of the teeth which is observable in a well-cut file. This sliding is also assisted by a little grease. All these motions are performed with astonishing rapidity: first the chisel, then the hammer, to the amount of between two and three hundred strokes, making as many teeth in a minute; in the larger files, however, which require heavier blows and deeper teeth, the number cut per minute is of course not so great.

Files receive particular denominations; first according to the rate of their teeth, and secondly according to their shape. Files of the very coarsest sort are called *rubbers*, and the next in order to these are called *rough* files, the next are called *bastard* cut, the next *second*

Machinery.
File cutting.

Manufac-
tures.

cut, the fifth *smooth*, and the finest of all *dead smooth*; when distinguished by their shape, we have, *flat*, *half-round*, *three-square*, *four-square*, and *round* files. The first are sometimes of uniform breadth and thickness throughout, they are also frequently tapering, the cross section being a parallelogram. The half-round is generally tapering, one side being flat and the other rounded, the cross section being a segment of a circle. The three-square is, in fact, an equilateral triangle in sections; these are mostly but not always tapering. The four-square file has, as its name imports, a square section. These are generally thickest in the middle, as is the case with the smith's rubber. In round files the section is a circle and the file is tapered.

The flat and square files are made entirely by the hammer. One man holds the hot bar and strikes with a small hammer, another stands before the anvil and strikes with a two-handed hammer, the latter having generally a very broad face for the larger files. These men, from continued practice, strike with such truth as to make the surface smooth and flat, without what is called hand hammering. The half-round and three-sided files are made in bosses; in the former the round part, and in the latter two sides, are formed by the boss, and the flat part by the hammer. The round files are formed by swages similar to those used by a common smith, but having a proper taper. The whole of the working part of the file is finished with the hammer before it is cut off from the rod, and the finished part is then held in tongs and heated a second time to form the fang of the file.

The first process files undergo after leaving the hammer is to soften them by annealing, for they are too hard in their former state, and too rough for the operation of cutting. The annealing is performed in troughs of fire-stone or fire-brick, similar to the cavities in which steel is converted, having the flame of the surface playing on every side and over the top. The trough is filled with alternate strata of the files and coal ashes, or the dust of the coaks formed in the forged hearth. The upper layer of files is covered by a thick stratum of dust, and lastly with a mixture of clay and sand, and the heat should be kept up no longer than till the mass becomes red hot quite through, and the whole is then left gradually to cool.

The next process is the preparation of the surface for the teeth of the files; this is effected differently in different places: in Lancashire it is done by filing, called there *stripping*; but in Sheffield the surface has no other preparation than grinding, which is done by Machinery and at a trifling expense, but by no means so well as by the Lancashire practice of stripping. We have already said what is necessary respecting the mode of cutting, and that between two hundred and three hundred blows and as many teeth are cut per minute. The smaller files are generally cut by women and children, who very soon acquire a great dexterity in the Art.

When the files are cut, the next process is to harden them. This is effected by heating them to redness and then quenching them in cold water; but some previous steps are taken to prevent the action of the oxygen of the atmosphere upon the file when red hot, and a peculiar method of immersing the file in the water is also observed. In the preparing process, ale grounds and common salt are used, the latter being in such proportion as to be just taken up by the aqueous part of the ale grounds,

that is, about three pounds of salt to a gallon. The Machinery files only require to be thinly smeared with this mixture, which, when dry, adheres firmly to the surface till the salt fuses. In heating the file for hardening, a fireplace or oven is formed into which the blast enters; two iron bearers are placed on the upper part of the cavity to support a number of files at once; these are heating gradually while a workman continues to select the hottest, and in a hotter part of the fire gives them the full degree of heat required for dipping them into the water. In this process, all files are dipped in a perpendicular direction: those, however, which have a round side and a flat one, are moved also in a horizontal direction with the round side foremost, without which precaution, files of this shape would warp towards the round side; this arises from the flat side having been more hammered than the round side, which is formed by the concave boss, and does not acquire the same density as is given by the hammer to the flat side. After being thus hardened, the files are brushed with water and coal dust. The surface becomes of a whitish-grey colour, and as perfectly free from oxydation as before heating. In this state they are ready for use.

(333.) *Engine for cutting screws.*—The more common method of cutting screws of the smaller kind, is by hand with taps and dies, which is too well understood to require minute description. To cut the external, or as it is sometimes called, the male screw, a die resembling a common iron nut is employed; but it is formed generally in two parts, and these are fixed in an iron box or die frame with two long handles; the die frame containing the two halves of the die is supplied with one or two screws, or other means whereby the two halves may be opened or closed at pleasure. These parts are formed of well-tempered steel, and the iron pin on which the screw is to be cut is first turned to a proper size; the dies are then opened, the end of the iron pin introduced, and the dies closed so as to take a pretty hard grip of the pin. The workman then, by means of the two handles above referred to, the pin being set fast in a vice, turns the whole round upon the pin, and thus produces a first impression of the thread already formed in the die. Having run the die thus once or twice from top to bottom of the pin, he sets up the dies a little closer by means of set screws, and by repeating the process gets a more defined thread; this is afterwards made still deeper by bringing the dies closer till the thread is properly formed. When an interior screw is to be cut, a proper sized cylindrical hole is first drilled, and then a steel tap slightly tapered, having a proper screw cut upon it and well tempered, is introduced; the head of this tap is left square, over which fits an iron bar with two handles, and by means of these the workman forces the tap down, first by pressing hard downwards and by gently turning at the same time, and thereby making a first impression of the thread. This now giving a direction to the tool, the effort of bearing down is less required, and ultimately a tap, which is throughout of the same dimensions, is introduced and the thread is completed. It may be well to observe that the tap is not cylindrical, as this would leave no cutting points; the tap, therefore, is formed on a pin first turned cylindrical, and which has afterwards segments filed off in two, three, or more sides; the thread being then cut upon it, and the tap properly hardened and tempered, the edges of these parts furnish so many cutting points for forming the interior thread of the female screw.

Manufac-
tures.

A similar principle to this is sometimes adopted to be worked by a steam engine or other power Machine. In these cases the dies are cut in four parts and placed in a frame, whereby they may be opened or closed at pleasure, the die frame is fixed in a strong cheek on the engine bed, and the bolt on which the thread is to be cut is made to revolve by means of the steam engine or other first mover. This bolt having passed through the dies the first time its whole length, the motion is reversed, the dies slightly closed by the workman in attendance, and the operation is repeated till the thread is properly formed. An apparatus of this kind is in constant use in his Majesty's smithery at Woolwich. In the same establishment is also another very excellent engine for the purpose of cutting the larger sort of screws to a great variety of pitches by means of a permanent screw of any pitch whatever.

Screw cut-
ting engine
in Wool-
wich dock-
yard.
Pl. xxiv.
Fig. 1 and 2.

(334.) This engine is represented in elevation and in plan in fig. 1 and 2, plate xxiv. Here A B, fig. 1, represent one side of a strong heavy cast iron lathe bed, both sides being seen in fig. 2, P, Q two heavy cast iron puppets, and C D an axle turning on a point at C, its end being countersunk in order to receive the point, the other bearing on a slightly conical collar in the puppet Q; the two bevelled wheels W W' fit on a part of the axle, and may either of them be thrown in or out of gear with the other bevelled wheel W'', seen in fig. 2, which receives its rotation from a steam engine shaft; S S are two standards on the side of the bed, in which turns in proper collar the screw s s, fig. 1, and the same on the other side, both being seen in fig. 2; E is a sliding frame, through a nut on each side of which the screws s s pass, so that as the screws revolve, this sliding frame is carried from one end of the bed to the other, and in this is fixed the tool by which the threads of the screw to be formed are cut. The cutter is secured in its place by means of the plates and nuts seen in fig. 2. Originally, another cutter was fixed on the opposite side, one having been intended to cut while the slider passed from the end A towards B, and the other as it returned from B towards A; but this arrangement was not found to answer its intended purpose, so that now only one cutter is employed, and the carriage returns free: the cutter is adjusted to its proper place by the screw and lever c d, seen in fig. 2, and the end of the same in fig. 1. T V is a sliding puppet carrying the back centre; this puppet may be placed in any part of the bed, and there screwed fast while any small adjustment for distance may be made by the screw G seen in fig. 2. The bolt or cylinder on which the screw is to be formed being turned perfectly true to two centres, one at each end, this is applied to the points in the mandrel and back centre, and a proper degree of contact is attained by means of the screw G. The end of the cylinder next to the mandrel D is properly secured; an iron chuck is placed on the mandrel, and by means of the driver well known in common lathes rotation is given to the cylinder; and in this form the apparatus may be used for any purpose in which a powerful lathe is required.

But when it is to be employed as an engine for cutting screws, a wheel *w* is fixed on the mandrel, and two equal wheels on the ends of the screws s s; so that while the cylinder revolves by means of the power communicated to the bevelled wheel by the engine, the wheel *w* gives a rotation to the wheels *w'*, *w''*; thus a horizontal motion is given to the slide rest or sliding frame from one end of the bed to the other, and the cutter being pushed forward by means of the screw a first

impression of a thread is formed in the revolving cylinder. When the frame arrives at the end of the cylinder, it presses on the stud *n*, on the lever *l*, and throws the wheel out of gear; a provision which is necessary for stopping the rotation at the proper place, as, without this, a moment's inattention of the workman would lead to the destruction not only of the cutting tool but of the whole apparatus. The tool being now brought back, the motion is reversed by bringing the other bevel wheel in gear, and the cutting frame returns. This wheel is now thrown out of gear by the frame itself, as at the other end; the tool is readjusted and made to cut deeper, and thus the operation is repeated till the screw is completed.

When the screw to be cut is to have the same pitch as the permanent screw which carries the slide rest, the three wheels *w*, *w'*, *w''* are all equal to each other, so that one revolution of the axle advances the cutter one thread; but by changing these wheels, so that the wheel *w* exceeds or falls short of the other two *w'*, *w''* in any ratio, the threads of the new screw may be made to differ from those of the permanent screw in the same ratio. It is therefore only necessary to have a variety of wheels, so arranged that the sum of their two radii shall be a given quantity, to fit the engine for cutting screws of any required pitch whatever.

When a screw is to be cut with a double thread, one thread is first cut, and then the driver is applied to a hole in the iron chuck, directly opposite to its first position; by this means a semi-rotation is given to the new screw, without producing any motion in the cutting frame, and consequently the cutter is now applied to a point midway between the two former threads, when by the same process as before this intermediate thread may be formed. If a triple thread be required, the driver is applied to a hole in the chuck, which is distant from its original position one-third of a circumference, and then again to another at two-thirds the distance, and in a similar manner any number of threads may be formed.

The apparatus for cutting the nut consists of a revolving cutter, turned on the principal axis while the nut itself is fixed in the slide rest, so that while the cutter revolves in its place, the nut gradually advances upon it, instead of the cutter advancing upon the thread as in cutting the screw.

(335.) *Engine for cutting original screws.*—The engine above described, although admitting of being set to cut a great variety of screws, cannot without a very large assortment of wheels cut a screw to any given pitch; and it is, moreover, after every variety that can by possibility be given, still dependent on a screw already formed; and this is generally the case with all our screw cutting engines. Great pains and ingenuity have accordingly been taken and employed to invent an engine that should be competent to cut an original screw, quite independently of any prior existing screw, and of any required pitch. One of the neatest and most perfect engines of this kind for short screws and taps, is erected in the Royal Arsenal at Woolwich, constructed, and we believe invented, by the late Mr. Adam Reid. Here the mandrel, between which and the back centre the cylinder to be cut is fixed, is turned by means of a winch and wheelwork, and on the mandrel is a toothed wheel which works in the teeth of a rack fixed on a long and broad plate of brass which slides between two vertical sides of a frame, faced very truly, so that while the screw is revolving, this brass plate is ascending between

Machinery

Cutting
original
screws

Manufac-
tures.

its guide rods, its breadth being about three inches, and length five feet. At the back of this plate is fixed on a pivot at its centre another similar plate or bar of the same length, and this may be inclined to the former at any angle from parallelism to any angle within the limits of the engine. This last movable rod projects beyond the back of the former and moves freely over it and the level face of the guides at its upper end; it is furnished with an arch head graduated, so that it may be inclined at any angle, and then by a set screw made fast to prevent any motion between the two rods.

A triangular bar parallel with the axis of the engine carries the slide rest or cutting tool; and this is made to come in contact with the inclined rod above described, so that by this means, as the cylinder to be cut is made to revolve, the bar between the two guides rises, and as this rises it brings up with it the inclined bar, and this pressing on the slide rest, urges it forward with greater or less speed according to the degree of its inclination with the vertical bar. If, for example, the swinging bar be fixed parallel with the original rising vertical bar, the slide rest will experience no pressure during the ascent, and the cutter will therefore remain at rest and will only cut a simple circular groove; but when inclined at any angle, the slide rest will during the whole ascent be urged forward a quantity equal to the opening of the two ends of the rod. But as the amount of this opening is much circumscribed by the limited length of the two bars, it is obvious that only very short screws can be cut, such indeed as can be of no use but for taps and guide screws. So that a perfect engine of this kind for long screws is still a desideratum.

Pl. xxiii.
Fig. 12.
Common
engine for
cutting
teeth of
wheels.

(336.) *Engine for cutting the teeth of wheels.*—A common tool for this purpose is shown in fig. 12, plate xxiii. which is found sufficiently accurate for wheels of a smaller kind, and where great precision is not required. Here A is the plate on which the teeth are to be cut; this is fixed concentric with the large brass plate H I, and the cutting is effected by the circular saw B, turned by the wheel and pinion C D, by means of the handle E, while the frame which holds the saw, moving on hinges and resting on a spring, is depressed by the handle F, the place having been previously adjusted by the screw G. The large plate H I contains a number of concentric circles, variously divided by points, into which the end of the spring I sinks at each step, so as to fix the apparatus in the required position, and thereby to equalize the distance and thickness of the teeth, which require afterwards to be finished off with a file.

Maudslay's
engine.

(337.) *Maudslay's engine for cutting teeth of wheels.*—This is an appendage to the lathe of this ingenious engineer. Here a brass plate, similar to that last described, has seventeen concentric circles upon it, each divided into a different number of equal parts, by small holes exactly of the same size; this forms the face of the mandrel, and a thin steel stop, similar also to that described above, adjustable by a screw, so that it may apply itself successively to the holes in any of the circles, is attached to one of the standards of the engine. The plate which is to form the wheel is fixed by means of a chuck to the mandrel, and turned true to its proper thickness and diameter. The fixed rest is then removed, and the slide rest substituted, in which a square bar is introduced having two projecting arms; and between these is placed a spindle carrying the cutters and a wheel, which latter, by being connected with the principal wheel of the lathe, gives a rapid rotation to the spindle on which the

cutters are fixed, *i. e.* to the amount of 7300 revolutions per minute. These cutters, which supply the place of the circular saw, consist of four chisels, fixed perpendicularly into the spindle or axle. The cutter being brought opposite the wheel, and adjusted to its proper distance, it is drawn back, the axle put in rapid rotation, and the whole frame made to advance by a screw for that purpose. Having cut out one tooth, the cutter is withdrawn, the mandrel turned till the pin takes the proper hole in the circle, when the cutter is again put in rapid rotation, and again advanced to the same point as before, cutting thus a second tooth; and thus the operation proceeds till the wheel is completed.

At that part of the frame of the cutting spindle, where the bar which is fixed to the slide rest connects with the two arms or branches, there is a joint by which the cutting spindle can be set in an inclined position for cutting oblique teeth, like those which are to work with an endless screw.

The great velocity with which the spindle turns, soon generates, by friction and resistance, a degree of heat sufficient to expand it very sensibly; but this ingenious mechanist, foreseeing this circumstance, has judiciously compensated for it in his construction, by making the spindle so short as to play loosely in its sockets at the commencement of the motion; but after a few seconds, the expansion is such as to cause the whole to fit together, and the work of cutting then proceeds with accuracy and safety.

(338.) Mr. Roberts, of the firm Sharp, Roberts, and Roberts's Co., of Manchester, has constructed an admirable engine ^{engine.} for this purpose, which cuts with the greatest accuracy and precision teeth of any dimensions, and on every description of wheel. It is impossible, without a great number of figures, to attempt any minute description of this truly ingenious piece of mechanism. We must, therefore, be content with stating, that it consists of a strong cast iron upright frame, carrying another frame, in which is supported the wheel, the teeth of which are to be cut, cast solid, and accurately turned and centred. This, by means of proper wheelwork and endless screw, is so arranged, that one complete revolution of a lever handle turns the wheel such an aliquot part of a revolution on its axis, as answers to the intended number of teeth, or the proper distance of one tooth from another; and by an ingenious contrivance, this lever handle can neither be stopped short nor passed beyond a complete revolution. The motion produced by this revolution on the wheel to be cut, may be varied at pleasure, by a great variety of wheels and pinions fitting each other, and calculated to bring out a great variety of numbers, as we have described in the screw cutting engine. (Art. 334.) By this means the equi-distances of the teeth are accurately insured. This being arranged, a small wheel, furnished with cutters, is put in rapid rotation by the strap from the steam engine, and advancing at the same time against the plain wheel, the first space is cut away. The workman then gives one complete revolution to the lever handle, which, as before stated, locks itself at the end of the revolution, but in no other part. This turns the wheel the distance of one tooth; the cutter is then again put in rotation and advanced, which cuts the second space, and thus forms the first tooth. Another complete revolution is then again given to the handle, and another space is cut, and of course another tooth is formed, and so on, with a rapidity and precision which is truly astonishing. And by giving to the several cut-

Machinery.

Manufac-
tures.

ters on the cutting wheel their proper figure, the working form of the tooth is at once obtained, which is a great advantage, for where this is left to be wholly effected by the file, it is impossible to arrive at that perfect regularity and uniformity of figure given in this way by the cutter.

In the above description, we have supposed the engine employed in cutting a common toothed wheel; and the reader must suppose the wheel placed vertically on its axis, with its face towards the cutters, these also running vertically, but at right angles to the face of the wheel, and so opposed to its lower circumference, as to cut the tooth of the proper or intended depth; but when a bevelled wheel is to be cut, the frame which supports the wheel is so formed as to admit of giving to the tooth any required inclination or bevel. The Machinery for effecting this is necessarily rather complicated, but it is so admirably executed that it works with the greatest accuracy and by means of proper graduations; it is set to any degree of inclination without a moment's consideration from the workman, beyond that of merely inquiring the number of teeth, their depth, and degree of bevel. It will of course have been understood, although not stated, that the cutting frame is adjustable, so as to operate upon wheels of every variety of diameters, from the largest to the smallest size employed in every description of Machinery.

Engine for
cutting key
ways.

(339.) The teeth being formed, and the wheel removed, a key way is generally required for keying the wheel upon its shaft. This is commonly effected by a cold chisel, and finished with a file; but in this Manufactory the file is but little employed, so that even this operation is performed by means of a cutter, worked by a Machine, which itself receives its motion from the main shaft of the engine. This operation is comparatively simple, as is also the engine by which it is effected. It consists of an upright strong cast iron frame, carrying a cutter or chisel, which descends vertically with great force. The wheel in which the key way is to be cut is placed beneath on a very solid bed, resting on a plate which may be advanced forward by a screw. Every thing being adjusted, so that the cutter in its descent just touches the inside of the hollow axis of the wheel, the latter is slightly advanced, and the cutter or chisel makes its first impression; the chisel now returns, the wheel is again advanced, and in its descent another shaving is removed, and so on, till a key way of the proper dimensions has been formed; by this means all the key ways of the same description of wheel are exactly of the same size, and the key to one will answer for any other. The same exactitude is obtained with all bolts, screws, and nuts, so that the usual precaution of numbering the corresponding parts is quite unnecessary in this establishment.

Hydraulic Engines.

Early hy-
draulic en-
gines.

(340.) Under this head are commonly included all those Machines which are employed in raising water from one level to another, and they are thus distinguished from those which are made to work by the force of moving water. Before the invention and perfection of the steam engine, a number of engines or Machines for the purpose of raising water from low levels, by means of other water descending from a high situation, and which might be discharged at an adit intermediate between the two, were invented, and form a conspicuous figure in our early books of Mechanics and Hydraulics; and even at

this time, when this object can be effected, it will frequently be preferred to steam power, because the power thus gained is obtained at little or no expense; for example, in working a mine, there may be an abundant supply of water at the surface, and at a certain depth an adit may either naturally exist, or may be formed, while a quantity of water may accumulate in the mine at a greater depth. In such a case, the surface water descending to the adit may be competent to work an engine sufficient to raise the lower water to the adit, and, therefore, if the Machinery be not too complicated, the draining may proceed at a very small expense. This, therefore, being the case, it will be proper that we enter in this place into a description of some of the more simple and useful of these engines, and, in particular, those which have not been described in our Treatise on THEORETICAL HYDRAULICS.

Machinery.

It is probable that the earliest mechanical contrivance for raising water was by means of a bucket and axle, as practised to the present day, when only an occasional supply is wanted for domestic or other purposes. This process would soon suggest to an ingenious mind that if two buckets were employed instead of one, the descending empty bucket would in part assist to raise the full bucket. The next step was to arrange a number of buckets, or vessels of some kind, on an endless rope, and then, by giving rotation to the axle, to obtain thereby a constant supply.

First means
of raising
water.

Such means as these are employed to the present day; and in the East, particularly in Egypt, where supplies of water are much required, there are scarcely any other. These Egyptian Machines consist of a number of earthen jars, suspended on an endless rope, which passes round a sort of drum, and when at their highest point, they empty their contents into a trough which carries them to a cistern; the drum is worked by a trundle and cog wheel, and motion is given to it by means of horses, asses, or cows. Something of a similar kind is also still used in Spain, known by the name of the *Noria*. This consists, like the Egyptian Machine, of a series of earthen

Method em-
ployed in
Egypt.

In Spain.

pitchers, connected by ropes, and turned by trundles or pinions, and buckets of wood are sometimes used in a similar manner. A bucket wheel is exactly the reverse of an overshot wheel, and the water here may be raised by buckets nearly similar to those which are calculated for receiving it in its descent in the former Machine. Various constructions are given to this kind of bucket wheel; in this Country a chain is substituted for the rope, and this chain varies considerably in its form and nature. Sometimes the buckets are hung on pins, so as to remain full during the whole ascent, but they are not very generally used, being liable to derangement, and to get out of repair. Sometimes instead of the reversed overshot wheel a reversed undershot wheel is used, or rather the breast wheel; in these cases the floats are worked by wind-mills, and are employed as a throwing wheel. These are most commonly confined to the draining of marshes, fens, &c.; the float boards are not placed in the direction which would be the best for an undershot wheel, but on the same principle, so as to be perpendicular to the surface when they rise out of it.

Bucket
wheel.

Instead of a series of buckets connected by a chain, a similar effect is sometimes produced by a simple rope, or a bundle of ropes passing over a wheel above and a pulley below, moving with a velocity of about eight or ten feet in a second, and drawing a certain quantity of

Hair rope
Machine.

Manufac-
tures.

water up by adhesion and capillary attraction. It is probable that the water commonly ascends with about half the velocity of the rope by comparing its relative velocity with that of a little river; but the rules which serve for computing the velocity of rivers, do not perfectly agree in this case with the results of direct experiments, for the friction required for elevating the quantity raised by such a Machine, appears by calculation to correspond to a velocity about twice as great as the actual relative velocity. While the water is principally supported by the resistance of the rope to its motion, its own adhesion is amply sufficient to prevent its wholly falling or being scattered by any accidental inequality of motion. This Machine being commonly composed of rope made of horse hair, is generally spoken of under the denomination of the *hair rope Machine*.

Archime-
des's screw,
&c.

Another method of raising water, which is frequently employed in excavations for docks, basins, &c., is the spiral pump; this consists of a system of spiral pipes placed on the plane of a wheel receiving the water at its circumference, and raising it by degrees, as the wheel turns, towards the axis, where it is discharged, the motion of the wheel being usually derived from steam or horse power; but the height to which the water is raised by this Machine, is very small in proportion to its bulk. A single pipe wound spirally round a cylinder, which revolves on an axis in an oblique situation, has been denominated the Screw of Archimedes, and is called in Germany the water snail. Its operation is like that of the flat spiral, and may be easily conceived by imagining a flexible pipe to be laid on an inclined plane, and its lower part to be gradually elevated, so that the fluid in the angle or bend of the pipe may be forced to rise; or by supposing a tube, formed into a hoop, to be rolled up the same plane, the fluid being forced, by the elevation of the tube behind it, to run as it were up hill. This instrument is sometimes made by fixing a spiral partition round a cylinder, and covering it with an external coating, either of wood or of metal; it should be so placed with respect to the surface of the water as to fill in each turn one half of a convolution, for when the orifice remains always immersed, its effect is much diminished. It is generally inclined to the horizon in an angle of between forty-five and sixty degrees; hence it is obvious that its utility is limited to those cases in which the water is only to be raised to a moderate height. The spiral is seldom single, but usually consists of three or four separate coils forming a screw, which rises slowly round the cylinder.

German
snail.

The *German snail* is an apparatus of nearly the same kind; it consists of a cylinder with its spiral projections detached from the external cylinder or coating within which it revolves. This Machine may be not improperly considered as a pump, but its operation is precisely similar to that of the screw of Archimedes. It is evident that some loss must here be occasioned by the want of perfect contact between the screw and its cover; and in general one-third of the water runs back, and the Machine cannot be placed at above thirty degrees of elevation. It is, moreover, easily clogged by accidental impurities in the water, yet it has been found to raise more water than Archimedes's screw, but it is more commonly employed on the Continent than in this Country.

Spira-
l pump.

When a spiral pipe, consisting of many convolutions arranged either in a single plane, or in a cylindrical or conical surface, and revolving round a horizontal axis, is connected at one end by a water-tight joint with an as-

cending pipe, while the other receives during each revolution nearly equal quantities of air and water, the Machine is called a spiral pump. It was invented about the year 1746 by Andrew Wirtz, a pewterer at Zurich, and is said to have been used with great success at Florence and in Russia; it was also employed in this Country by Lord Stanhope, and has been made to raise water to the height of forty feet by the late Dr. Young.

The end of the pipe is furnished with a spoon, containing as much water as will fill half of the coil, which enters the pipe a little before the spoon has arrived at its highest situation, the other half remaining full of air, which communicates the pressure of the column of water to the preceding portion; and in this manner the effect of nearly all the water in the wheel is united, and becomes equivalent to that of the column of water, or of water mixed with air in the ascending pipe.

The air nearest to the joint is compressed into a space much smaller than that which it occupied at its entrance, so that where the height is considerable, it becomes advisable to admit a larger portion of air than would naturally fill half the coil, and this lessens the quantity of water raised, but it lessens also the force required to turn the Machine. The joint ought to be conical so that it may be tightened when it becomes loose, and the pressure ought to be removed as much as possible. The loss of power, supposing every thing well constructed, arises only from the friction of the water along the pipe, and the friction of the wheel on its axle; and where a quantity of water has to be raised to a moderate height, both of these resistances may be rendered inconsiderable, but when the height is very great the length of the spiral must be increased, so that the weight of the pipe becomes extremely cumbersome and causes a great friction on the axle as well as strain upon the Machinery. Thus for a height of forty feet, Dr. Young found that the wheel required above one hundred feet of pipe, which was three-quarters of an inch in diameter; and more than one half of the pipe being always full of water, it was necessary to overcome the friction of above eighty feet of such a pipe, which requires twenty-four times as much excess of pressure to produce a given velocity as if there were no friction. The centrifugal force of the water in the wheel would also materially impede its ascent if the velocity were considerable, since it would be always possible to turn it so rapidly as to throw the whole water back into the spoon. It appears that the Machine more particularly alluded to above, which was constructed for Dr. Young did not answer its purpose, or was not found so efficient as was expected of it, for it having got out of repair, this Philosopher thought it more eligible to replace it by a common forcing pump. But he observes, if the wheel and its pipes were entirely made of wood it might in many cases succeed better; or the pipes might be made of copper tinned, or even of earthen-ware, which would be cheaper and lighter than lead.

It has been stated that besides these simple Machines described above, and the various forms of pumps which have been from time to time invented, some of which will be described in a subsequent page, several very ingenious but rather complex engines have been contrived in which water is the moving power, as well as the body raised; that is, the fall of a body of water from a high level, which discharges itself at a certain adit, is made to raise water from a low level to that of the adit. We do not think, however, that it would be advisable to

Machinery.

Manufac-
tures.

engage the reader's attention with a description of the several curious contrivances of this kind which are rather local than general, and many of them more ingenious than useful, beside the most valuable of them have been already illustrated in our *Theoretical Treatise on HYDRAULICS*. We shall therefore in this place confine our description to only one of them which was some few years back erected at one of our Cornwall mines.

Pressure
engine.

Pl. xxvii.
Fig. 1.

(341.) *Pressure engine*.—This is an invention of the late ingenious Mr. Trevethick, but in principle it does not greatly differ from other Machines executed in France many years back, and described by Belidor in his *Arch. Hydraul.* lib. iv. ch. i. Mr. Trevethick's engine, however, is more complete, and is very ingenious; it was first employed at the Druid copper mines in the parish of Illogan near Truro. This engine is represented in plate xxvii. fig. 1, where A B is a pipe six inches in diameter, through which water descends from the head to the place of its delivery, to run off at the adit S through a fall of thirty-four fathoms in the whole; that is to say, in a close pipe down the slope of a hill two hundred fathoms long, with twenty-six fathoms fall, then perpendicularly six fathoms, till it arrives at B, and thence through the engine from B to S two fathoms. At the turn B the water enters into a chamber C, the lower part of which terminates in two brass cylinders *a* and *b*, in which two plugs or pistons of lead D and E are capable of moving up and down by their piston rods, which pass through a close packing above, and are attached to the extremities of a chain leading over and properly attached to the wheel Q, so that it cannot slip.

The leaden pieces D and E are cast in their places, and have no packing whatever. They move very easily, and if at any time they should become loose, they may be spread out by a few blows with a proper instrument, without taking them out of their places. On the sides of the two brass cylinders, in which D and E move, there are square holes communicating towards F and G, which is a horizontal trunk or square pipe, four inches wide and three inches deep. All the other pipes, G, G, and R, are six inches in diameter, except the principal cylinder wherein the piston H moves; and this cylinder is ten inches in diameter, and admits a nine-foot stroke. The piston rod works through a stuffing box above, and is attached to M N, which is the pit rod, or a perpendicular piece divided into two, so as to allow its alternate motion up and down, leaving a space between without touching the fixed apparatus or great cylinder. The pit rod is prolonged down into the mine, where it is employed to work the pumps, or if the engine were applied to millwork or any other use, this rod would form the communication with the first mover.

K L is a tumbler or tumbling-bob, capable of being moved on the gudgeons V from its present position to another, in which the weight L shall hang over with the same inclination on the opposite side of the perpendicular, and consequently the end K will then be as much elevated as it is now depressed.

The pipe R S has its lower end immersed in a cistern, by which means it delivers its water without the possibility of the external air introducing itself; so that it constitutes a Torricellian column or water barometer, and renders the whole column from A to S effectual; as will be seen in the following view of the operation.

The operation.—Let us suppose the lower bar K V of the tumbler to be horizontal, and the rod P O so

situated that the plugs D and E shall lie opposite to each other, and stop the water way G and F. In this state of the engine, though each of these pistons is pressed by a force equivalent to more than a thousand pounds, they will remain motionless, because these actions being contrary to each other, they are constantly in equilibrio. The great piston being here shown as at the bottom of its cylinder, the tumbler is to be thrown by hand into the position delineated in the figure. Its action upon O P, and consequently upon the wheel Q, draws up the plug D, and depresses E so that the water way G becomes open from A B, and that of F to the pipe R; the water consequently descends from A to C, thence to G G G, until it acts beneath the piston H. This pressure raises the piston, and if there be any water above the piston, it causes it to rise and pass through F into R. During the rise of the piston (which carries the pit rod M N along with it) a sliding block I, fixed to this rod, is brought into contact with the tail K of the tumbler, and raises it to the horizontal position, beyond which it oversets by the acquired motion of the weight L. The mere rise of the piston, if there were no additional motion in the tumbler, would only bring the two plugs D and E to the position of rest, namely to close G and F, and then the engine would stop; but the fall of the tumbler carries the plug D downwards quite clear of the hole F, and the other plug E upwards quite clear of the hole G. These motions require no consumption of power, because the plugs are in equilibrio, as is above observed.

In this new situation the column A B no longer communicates with G, but acts through F upon the upper part of the piston H and depresses it; while the contents of the great cylinder beneath that piston are driven out through G G G, and pass through the opening at E and R. It may be observed, that the column which acts against the piston is assisted by the pressure of the atmosphere, rendered active by the column of water hanging in R, to which that assisting pressure is equivalent, as already noticed.

When the piston has descended through a certain length, the slide or block at T upon the pit rod applies against the tail K of the tumbler, which it depresses, and again oversets; producing once more the position of the plugs D E. delineated in the figure, and the consequent ascent of the great piston H, as before described. The ascent produces its former effect on the tumbler and plugs; and in this manner it is evident that the alternations will go on without limit, or until the manager shall think fit to place the tumbler and plugs D E in the position of rest; namely, so as to stop the passage F and G.

The length of the stroke may be varied by altering the positions of the pieces T and I, which will shorten the stroke the nearer they are together; as in that case they will sooner alternate upon the tail K.

As the sudden stoppage of the descent of the column A B, at the instant when the two plugs were both in the water way, might jar and shake the apparatus whose plugs are made half an inch shorter than the depth of the side holes, so that, in such case, the water can escape directly through both the small cylinders R, this gives a moment of time for the generation of the contrary motion in the piston and the water G G G, and greatly deadens the concussion which might otherwise be produced. Some former attempts to make pressure engines upon the principle of the steam engine

Machinery

Manufac-
tures.

have failed; because water not being elastic, could not be made to carry the piston onwards a little so as completely to shut one set of valves and open another. In the present judicious construction, the tumbler performs the office of the expansive force of steam at the end of the stroke.

It has been suggested, as a considerable improvement, that the action of this engine should be made elastic by the addition of an air chamber, on the same principle as that used in fire engines: this, it was thought, might be best effected by making the piston hollow, with a small orifice in the bottom, and of a larger size, to serve for this purpose, as the spring of air would then act both on the upward and downward pressure of the water. We are not aware, however, that this suggestion has been adopted. Gregory, *Mechanics*.

Hydraulic
ram.

(342.) In our Theoretical Treatise on HYDRODYNAMICS an ingenious application of a running stream for the purpose of raising water has been described under the denomination of the Hydraulic Ram. It is only referred to again in this place for the sake of arrangement, and to avoid the necessity of referring the reader to the volume in question. The effect is here produced by the momentum of a stream of water flowing through a long pipe. The passage of the pipe being stopped by a valve, which is raised by the stream as soon as its motion becomes sufficiently rapid, the whole column of fluid must necessarily concentrate its action almost instantaneously on the valve; and in this manner it loses the characteristic property of hydraulic pressure, and acts as if it were a single solid, so that supposing the pipe to be perfectly elastic and extensible, the impulse must overcome any pressure, however great, that might be opposed to it; and if the valve open into a pipe leading to an air vessel, a certain quantity of the water will be forced in, so as to condense the air more or less rapidly, to the degree that may be required for raising a portion of water contained in it to any given height. The first application of this ingenious idea is due to an Englishman of the name of Whitehurst; it was afterwards improved by Mr. Boulton. It was again reinvented or copied by some French engineers, and lastly, was brought out under a new character, and with all the parade of a new discovery, by Mr. Mongolfier, the ingenious inventor of the rarefied air balloon.

It has been stated above, that hydraulic engines are very numerous, and of various forms and construction; but we do not think it would be advantageous to the reader to engage his attention, and to occupy our pages and plates with a description of them; they are frequently fitted to answer particular purposes, and do not admit of general application; they are, moreover, superseded in most cases by the steam engine, which is of general application. A few references, however, to Works in which they are described may be useful; we therefore give the following as the best authorities.

(343.) Belidor, *Architec. Hydraul.* vol. ii.; Desaguliers, *Experimental Philosophy*; Hautefeuille, *Réflexions sur quelques Machines à élever les Eaux*; Leupold, *Theatri. Machinarum Hydraulicarum*; The *Phil. Trans.* 1685, 1731, 1734; *Memoirs of the Berlin Academy*, 1750, 1751, 1752; *Memoirs of the Academy of Paris*, 1754, 1763; *The Academy of Petersburg*, 1772; Coulomb, *Researches in Hydraulics*, 1779; Prony, *Nouve le Architecture Hydraulique*, 1790, 1796. See also Gregory, *Mechanics*, vol. ii.

Pumps.

(344.) *Pumps*.—Of all hydraulic engines the pump is

the most common and the most varied in its form; indeed, Machinery the term pump has not uncommonly been extended to hydraulic engines of all descriptions; but the term in its strictest sense is to be understood only of those Machines in which the water is raised by the action of a piston working in a case or cylinder, either on the principle of pressure or suction.

(345.) The theory of both kinds of pumps has been already given in our Treatise on HYDRODYNAMICS; our business here, therefore, is only with their practical application and construction. The simplest kind of pump is that which is worked by a solid plunger; but it requires to have a double barrel to make it advantageous, and is then most applicable to raising water only to small heights. It has been made by fitting two upright beams or plungers of equal thickness throughout into cavities nearly of the same size, allowing them only sufficient room to move without friction, and connecting the plungers by a horizontal beam moving on a pivot. The water being admitted during the ascent of each plunger by a large valve in the bottom of the cavity, it is forced, when the plunger descends, to escape through a second valve in the side of the cavity, and to ascend by a wide pipe to the level of the beam. The plungers ought not to be in any degree tapered, because of the great force which would be unnecessarily consumed in continually throwing out the water with great velocity as they descend, from the interstice formed by their elevation. This pump may be worked by a labourer walking backwards and forwards, either on the beam, or on a board suspended below it. By means of an apparatus of this kind, described by Professor Robison, an active man, loaded with a weight of thirty pounds, has been able to raise 580 pounds of water every minute to a height of eleven feet and a half, for ten hours a day, without fatigue; this is the greatest effect produced by a labourer that has ever been correctly stated by any author; it is equivalent to somewhat more than eleven pounds raised through ten feet in a second, instead of ten pounds, which is a fair estimate of the usual force of a man, without any deduction for friction.

It is obvious that if the plungers were so well fitted to the cavity as to prevent the escape of any water between them, the ascending pipe might convey the water to any required height. The engine would then become a forcing pump, and the plungers might be shortened at pleasure, so as to assume the form of a piston sliding within a barrel. The piston might also be situated above the level of the reservoir, and in this case the water would be forced up after it by the pressure of the atmosphere to the height of about thirty feet, but not much further; and even this height would be somewhat too great for practice, because the water might sometimes follow the piston in its ascent too slowly. Such a pump partakes of the nature of a forcing and sucking pump, and is called a mixed pump. In Delahire's pump, the same piston is made to serve a double purpose, the rod working in a collar of leathers, and the water being admitted and expelled in a similar manner, above and below the piston, by means of a double apparatus of valves and pipes.

(346.) For forcing pumps of all kinds, the common piston, with a collar of loose and elastic leather, is preferable to those of a more complicated structure; the pressure of the water on the inside of the leather makes it sufficiently tight, and the friction is inconsiderable. In some pumps the leather is omitted, for the sake of simplicity,

Simple
forcing
pump.

Manufac-
tures.

the loss of water being compensated by the greater durability of the pump; and this loss will be the smaller in proportion as the motion of the piston is more rapid.

Simple
sucking
pump.

In the common sucking pump, the valve through which the water escapes is placed within the piston itself, so that the same barrel serves for the ascent of the water, which rises in one continued line while the piston is raised, and rests on the fixed valve while it is depressed. The velocity of the stroke ought never to be less than four inches in a second, nor greater than two or three feet; the stroke should also be as long as possible, in order to avoid unnecessary loss of water during the descent of the valve. The diameter of the pipe, through which the water rises to the barrel, ought not to be less than two-thirds of the diameter of the barrel itself.

A bag of leather has also been employed for connecting the piston of a pump with the barrel, and in this manner nearly avoiding all friction; but it is probable that the want of durability would be a great objection to such a Machine.

Where the height through which the water is to be raised is considerable, some inconvenience might arise from the length of the barrel through which the piston rod of a sucking pump would have to descend, in order that the piston might remain within the limits of atmospheric pressure. This may be avoided by placing the movable valve below the fixed valve, and introducing the piston at the bottom of the barrel. Such a Machine is called a lifting pump; but in common with other forcing pumps, it has the disadvantage of thrusting the piston before the rod, and thus tending to bend the rod, and produce an unequal friction on the piston, while in the sucking pump the principal force always tends to straighten the rod.

The rod of a sucking pump may also be made to work in a collar of leather, and the water may be forced through a valve into an ascending pipe. By applying an air vessel in this, or to any other forcing pump, its motion may be equalized and its performance improved; for if the orifice of the air vessel be sufficiently large, the water may be forced into it during the stroke of the pump, with any velocity that may be required, and with little resistance from friction, while the loss of force, from the frequent acceleration and retardation of the whole body of water in a long pipe, must always be considerable. The condensed air reacting on the water expels it more gradually, and in a continual stream, so that the air vessel has an effect analogous to that of a fly wheel in Mechanics.

The pipes through which water is raised by pumps of any kind ought to be as short and as straight as possible; thus, if we had to raise water to a height of twenty feet, and to carry it to a horizontal distance of one hundred feet by means of a forcing pump, it would be more advantageous to raise it first vertically into a cistern twenty feet above the reservoir, and then to let it run along horizontally, or find its level in a bent pipe, than to connect the pump immediately with a single pipe carried to the place of destination. And for the same reason a sucking pump should be placed as nearly over the well as possible, in order to avoid a loss of force in working it. If very small pipes are used, they will much increase the resistance by the friction which they occasion.

(347.) Water has sometimes been raised by stuffed

cushions or by oval blocks of wood, connected with an endless rope, and caused by means of two wheels or drums, to raise in succession in the same barrel, carrying the water in a continual stream before them; but the magnitude of the friction of the cushions appears to be an objection to this method. From the resemblance of the apparatus to a string of beads, it has been called a bead pump, or paternoster work. When flat boards are united by chains, and employed instead of these cushions, the Machine may be denominated a cellular pump; and in this case the barrel is usually square, and placed in an inclined position, but there is a considerable loss from the facility with which the water runs back. The chain pump generally used in the Navy is a pump of this kind, with an upright barrel, through which leathers, strung on a chain, are drawn in constant succession; these pumps are only employed when a large quantity of water is to be raised, and they must be worked with considerable velocity, in order to produce any effect at all. An improved construction of the chain pump, so as materially to increase the quantity of water raised by it, is described in a subsequent article.

(348.) It is frequently necessary to procure alternate motion in pumps by means of wheelwork; and for this purpose the application of a crank is the most usual, and perhaps the best method. Provided that the bar by which it acts be sufficiently long, very little will be lost by the obliquity of its situation, and it is easy, by means of rollers, or of a compound frame, to confine the head of the pump rod to a rectilinear motion. When any other mode is employed, it must be remembered that the motion of the pump rod ought always to be slower at the beginning of each alternation, since a considerable part of the force is consumed in setting the water in motion, especially where the pipe is long and the velocity considerable. But it may happen that, from the nature of hydraulic pressure under other circumstances, the resistance may be nearly equal throughout the stroke; for example, when the motion of the piston is slow, in comparison with that of the water in the pipe, or when the force employed in producing velocity is considerable in comparison with that which is required for counteracting the pressure. In such cases it may sometimes be eligible to employ inclined surfaces, of such forms as are best adapted to communicate the most advantageous velocity to the pump rod by their pressure on a roller, which may be confined to its proper direction by the same means as when a crank is used. The Chinese work their cellular pumps or bead pumps by walking on bars which project from the axle of the wheel or drum that drives them, something after the manner of our tread-mill; and whatever objection there may be to the pump itself, the mode of communicating the motion to it must be allowed to be ingenious and advantageous.

Pumps have sometimes been worked by means of the weight of water acting within a barrel, which resembles a second pump placed in an inverted position; this is somewhat similar to the engine described in the preceding article under the denomination of the Pressure Engine, by Trevethick, the principle of which, as we have stated, is very nearly the same with that described by Belidor, and known in Germany under the name of Hüll's Machine.

(349.) Amongst other ingenious ideas connected with the subject of raising water, we ought to mention that which has been suggested for effecting this object by the spontaneous vicissitudes of the pressure of the air, occasioned

Raising
water by
changes of
pressure in
the atmo-
sphere.

Machinery.

Paternos-
ter work.

Pumps
worked by
cranks.

Manufactures.

by changes in the weight and temperature of the atmosphere by means of a series of reservoirs furnished with proper valves. But it seldom happens that such changes are capable of producing an elevation of water in each reservoir of more than a few inches, or at most a foot or two in a day, and the whole quantity raised, therefore, must be very inconsiderable.

Centrifugal pump.

(350.) Another hydraulic engine commonly considered to belong to this class, is the centrifugal pump. This is the reverse of Barker's mill. It consists of a vertical pipe, caused to revolve round its axis, and connected above with a horizontal pipe, which is open at one or at both ends, the whole being furnished with proper valves to prevent the escape of the water when the Machine is at rest. As soon as the rotation becomes sufficiently rapid, the centrifugal force of the water in the horizontal pipe causes it to be discharged at the end, its place being supplied by means of the pressure of the atmosphere on the reservoir below, which forces the water to ascend through the vertical pipe. It has also been proposed to turn a Machine of this kind by the counterpressure of another portion of water, where there is fall enough to carry it off. This engine may be so arranged, that, according to theory, little of the force applied shall be lost; but it has failed of producing in practice a very advantageous effect.

Having given above a concise account of the more simple description of pumps and the principles on which they act, it remains now for us to describe some peculiarities introduced into the mechanism by which these principles are brought into action.

Taylor's sucking pump. Pl. xxviii. Fig. 1.

(351.) In the course of the preceding observations, reference has been made to different ways of working the piston, and the following has been much recommended for the little friction it produces. Plate xxviii. fig. 1, is a vertical section of this pump. The piston rods have racks at their upper parts working on the opposite sides of a pinion and are kept to their proper position by friction rollers. The valves used in this pump are of three kinds, as shown at *a, b, c*. The former is a spheric segment which slides up and down on the piston rod, and is carried down by its own weight; the second *b* is called the pendulum valve; and the third *c* is a globe which is raised by the rising water, and falls again by its own weight. Each of these valves will disengage itself from the chips and gravel, &c. brought up by the water. In this kind of pump the piston may be put in motion by a handle in the usual way, or a rope may pass round the wheel *d e* in a proper groove, the two ends of which, after crossing at the lower part of the wheel, may be pulled by one or more men on each side. A pump of this kind, of seven inches bore, is said to be capable of lifting a ton of water to the height of twenty-four feet in a minute when worked with ten men, five on each side.

Stephens's forcing pump.

(352.) A forcing pump of a very ingenious description is represented in plate xxvii. Here fig. 2 is the section of a well in which a pump of this kind is fixed. A A represent the surface of the ground, and B B the brick-work of the well, in which the water stands at the level C, and is, by the pump, to be raised to the surface A A.

D is a lever or handle of the pump, which has the part *a* jointed to it and descending to the pump; the rod is made of wood, in several lengths, which are united by joints of iron, in the manner shown in fig. 3, the wooden rods *a a* being capped with iron forks *b*, which include the ends of them, and are rivetted fast; the ends of the forks are jointed together to connect the

several lengths. E is the working barrel or chamber of the pump, in which the bucket *d* works; this path is formed of a tree, bored through, and having a projecting branch *e*, which is likewise bored obliquely to the barrel, and forms the forcing pipe; in the bottom of the barrel the suction valve *f* is situated, being at the top of the suction part of the pump, which is bored with a smaller auger than the working chamber, which is also lined with a brass tube where the bucket works. The top of the barrel is covered by a metal lid *g*, (see also fig. 4 and 5,) which has a stuffing box in the centre to receive the metal cylindrical part of the pump rod *h*; to the lower extremity of this the bucket *d* is fixed. The metal lid consists of a ring, which is screwed to the wooden barrel by five screw bolts, passing through as many ears, projecting from the circumference of the ring; they have eyes below to hook upon pins, which are fixed in the wood, but project sufficiently for these bolts to hold the ring firmly down, by means of nuts screwed upon them. The movable lid of the pump, which has the stuffing box *g* formed in the centre of it, is screwed to the ring by five screws, and these can be taken out to remove the lid, and draw up the bucket when it requires to be leathered.

F is the forcing pipe, formed of as many pieces of wooden pipes as are required to make up the length; they are united together by making the upper ends conical, to enter a similar cavity made in the lower end of the next pipe; the lowest piece fits upon the extremity of the projecting branch *e*, and a valve is proposed to be put in the pipe, at this joint, to prevent the return of the water, and bear part of the weight of the column from the lowest valve at *f*; the upper length of the pipe has a spout *i* at which the water is delivered.

N is a second spout fixed into the pipe lower than the former; it has a screw by which it can be united to a hole, or leathern pipe, to convey the water to a distance, or by means of a jet or branch pipe to throw it in the manner of a fire engine; in this case the upper spout *i* must be stopped up by a screw plug or cap; and there is a copper air-tight vessel H situated at the top of the pipe F, to equalize the pulsative motion of the water as thrown by the pump.

k is a bracket fixed to the pipe F, and projecting over the centre of the pump, where it has a hole to receive the pump rod *h*, and guide it steadily in its motion up and down, that it may not wear the stuffing box away on one side. As the wooden tubes of which the forcing pump F is composed, may be made from waste or crooked timber, it makes a great difference between the low price of such, and that of the straight trees necessary for common pumps.

A wooden plug may be chained to the pump betwixt the spouts or nozzles M and *i*, so as to be ready to stop that which is not wanted in use.

Mr. Stephens is of opinion, that it is better to place the valve *f* above the level of the water in the well. *Society of Arts*, vol. xxxii.

(353.) Hedderwick's double piston pump.—The general character of double piston pumps is to have the piston rods attached to one side of the pistons, which has a tendency to give an unequal pull upon them, whereas in this contrivance they are attached to the centre of the piston, the lower piston rod passing through the centre of the upper piston.

The method of doing this is more particularly shown

Hedderwick's double piston pump.

Manufactures. in fig. 2, 3, and 4, pl. xxviii. In fig. 3, K K, D D, is part of the piston rod of the other piston with two branches D D joined at D D to the piston F F.

Pl. xxviii. Fig. 2, 3, 4. G G is part of the piston rod of the lower piston, passing through the cross bar F F, which is attached to the top of the upper piston; E E is another cross bar by which the piston rod G G passes.

The joined pistons here shown are only necessary in large pumps. In smaller ones, the joint D and the bar E E may be dispensed with, and thus the piston rod may be all in one piece, fastened to the top of the piston box at F F, the pliancy of the rods rendering the joint at D needless.

Fig. 4 represents the top of the piston with the cross bar F F, through which the lower piston rod G G, fig. 3, passes. The two valves are formed of one piece of leather in the usual manner, which is confined under the bar or cross piece F F, and is strengthened by having two plates of iron rivetted upon it, one on each valve, the valves being what are usually termed butterfly valves.

The principle of action will appear from the manner of working the pump as follows:

In fig. 2, A D H is a handle or bent lever upon one side, and L K I is a similar one on the other side of the pump, by which the power is communicated to the pistons; the lever A D H is movable round the fulcrum or centre D, and the lever L K I round the centre K; the extremities I and H are connected by a bar I H, so that when the end of the one lever A is depressed, the other is raised; the parts A D and L K of the levers are continued to E and O beyond their centres of motion D and K, so as to be as nearly over the centre of the bore of the pump as possible, but free of each other in the operation of working.

By this connection, when the handle A is depressed, the handle L is raised, the piston G is depressed, and the other piston F raised. This motion being reciprocally continued, gives a double advantage in lifting the water; for, when the one handle is pulled down, the piston attached to that handle is raised, and when the same handle is raised up, the piston belonging to the opposite handle is also raised.

From the construction of this pump with two pistons, it appears evident that the pump barrel would raise twice as much water in the same time as two others of equal bore with one piston each; a benefit of sufficient importance in many cases of accidents at sea. But upon a comparative trial before the Committee of Mechanics appointed by the Society of Arts, (to which the plan was submitted by the inventor,) it turned out that the pump with two pistons actually raised twice and a half as much water as another pump with one piston only, which was connected with it so as to make equal strokes therewith, did in the same time; a difference in favour of the pump with two pistons so remarkably great, as to occasion doubts in the minds of the Committee whether the pistons or bore of the double piston pump might not have been more accurately formed than in that with a single piston. On this account they shifted the pistons from the one barrel to the other, but, on repeating the experiment, the result was the same as before; a convincing proof that the experiment was a fair one. And, in fact, the difference in the effect of the two pumps can be perfectly well accounted for by the consideration that in the pump with a single piston, the water, after being put into motion by the action of the

Machinery. pump, is suddenly stopped by the change of motion during the descent of the piston, and has to be again put into motion at every stroke of the pump, to the great hinderance of the regular discharge of the water; whereas in the pump with two pistons the flow from it is nearly continual during its action, the one piston constantly ascending whilst the other is descending, and the momentum of the water continuing its ascent during the change of motion in the pistons, and thus producing the very great difference in favour of the performance of the pump with two pistons; neither does this pump ever require double the force that is applied to one with a single piston to work it, it being much easier to continue a motion when commenced, than to renew it perpetually when interrupted, as it is in the pumps with one piston only.

(354.) *Franklin's double piston pump.*—This Machine Franklin's double piston pump. also is one presented to and rewarded by the Society of Arts. See *Trans.* vol. xxxiii. Here A A are two pistons, on the upper surface of each is a double valve, v v v v; the upper piston passes through the stuffing box B, and the lower through the stuffing box C; S is the suction pipe, and D the discharging pipe.

Fig. 7 is an external view of the pump; e e e the lever or handle; F the fulcrum, on which the handle moves; G G the pump cylinder; W W the wheels which revolve between the standards X X, and which conduct the piston rods parallel to the cylinder; e P the conducting rod which conveys the motion of the handle to the lower piston; e O the conducting rod which gives motion to the upper piston. It is evident when the handle or lever is lifted, that the upper piston is pressed down, and the lower piston is at the same time elevated, and its valves shut, which forces the water through the upper piston and the discharging pipe at the same operation. And when the handle is pressed down, the upper piston rises with its valves closed, and the water, in its ascension, is forced through the discharging pipe; at the same time, the lower piston descends, by which action its valves are opened, and introduces a supply of water equal to the contents of the cylinder, minus the capacity of both pistons. The peculiar advantages of this pump with double pistons are, that with a six-inch stroke it discharges a quantity of water equal to twelve inches of the cylinder; and so, in this proportion, by always doubling the quantity of the stroke, whatever it may be; and thus furnishing a product just equal to two common pumps of the same stroke and capacity of cylinder, and certainly with less than a proportionable friction and expense. Fig. 6 is an enlarged section of the cylinder G G, fig. 7, showing the valves V V.

(355.) *Pumps for ships.*—When the desperate consequences attending the gradual sinking of a vessel at sea which has sprung a leak are considered, it will be readily admitted that a good ship pump is an engine of the utmost importance, and that too much care and attention cannot be paid to rendering it effective and powerful. It is not therefore extraordinary to find that almost every description of pump has been tried on shipboard; but that which seems to have been preferred is the chain pump, of which there are still some varieties; but beside the chain pumps, all ships in the British Navy are supplied with hand pumps. The larger class of ships of war have four of the former, and three of the latter class, all communicating with one well: one of the hand pumps, called the wash deck pump, being used to raise water from a cistern in the hold to the

Manufac-
tures.

upper deck for the purposes of washing the decks; but it is also applicable on emergency for pumping the ship. Several kinds of hand pumps have been proposed for this purpose, the first of any notoriety having been the invention of Benjamin Martin, the well-known author of several ingenious popular Works on Philosophical and Mathematical subjects.

Smeaton's
ship pump.

(356.) Mr. Smeaton also projected a pump for this purpose which is described in the first volume of his *Reports*. He there observes that the common ship pump generally delivers its water upon the main deck, which, according to the size and construction of the ship, is four, five, or more feet above the surface of the ocean, or load water line, while this line itself is not more than from 14 to 18 feet above the ship's bottom; consequently the common pump lifts the water one-third or one-fourth higher than is necessary. He proposed, therefore, wooden trunks or pipes, proceeding horizontally from the upright trunk of the pump, to carry off the water through the ship's side, and fitted at the other end into bores or short working tubes, just above the said line. These side pipes to be closely jointed with the boxes in the ship's side at one end, and at the other end into strong planks bolted against the sides of the pump, in order that the side pipes might be got out and in without disturbing the pump, which was of the sucking kind, its piston or bucket having been worked by a lever or brake upon the deck over the pump itself. From its top a stand pipe was carried up to the main deck, or as high as was thought necessary, to prevent the water reverting and returning back into the ship over the top of the pump, when the sea rose above the orifices of the side pipes, or when, from the ship being in distress, they were under her load water line. By this means, when even both boxes and pipes were under water, it would in no way interrupt the action of the pump, for whenever the water in the stand pipe rose above the level of the water without, the pressure of the column in the stand pipe would cause it to make its way through the side pipes, so that in this case no level was lost, and, although the pump should be at rest, no water could revert down the pump, because there were both bucket and fixed box, or clack, which prevented it. The working barrel was of brass, and very truly bored; both the bucket and fixed box having been of the same construction as those used in steam engines—or, as Smeaton always denominated them, fire engines—and the pump rod was made of greater bulk than was necessary, merely for strength, in order to furnish weight, whereby when the brake was lifted up, the pump rod should readily descend by its own weight. The brake of the pump had a branch fixed on rather obliquely on each side, so as to form three handles for four men to work at one time; these stood one on each side of the middle stem of the brake, and one on the outside of each branch handle, and every quarter of an hour they could relieve themselves by changing hands, which was done by changing places. It was intended that the number of strokes per minute should not exceed twenty-five, the length of each stroke being $17\frac{1}{4}$ inches, and the barrel a nine-inch bore, which was considered to be better than making shorter and quicker strokes, as was the case in the older pumps. The men's hands moved up and down about four feet six inches, and by working with this stroke at a moderate rate, so as to hold it on an hour, four men would in that time deliver 20 tons at a height of 22 feet. This was upon a supposition of

raising the water to the usual height; but when, by the application of the maxim before described, this perpendicular was shortened to 16 or 17 feet, then nearly the same delivery could be made by three men, or proportionably more by four men, that is, as 17:22::20:26 tons at 17 feet. The foot of the pump was let through the ship's inner planking or ceiling, betwixt two of the floor timbers, and did not touch the bottom or outside planking within $2\frac{1}{2}$ inches, with the lower end rounded withinside like a trumpet mouth, it being supposed a bad plan to have the pump standing upon its lower extremity, with holes bored to let in the water, as it is thus very liable to be choked by dirt. A plank of the ceiling was made to lift up near the pump's foot, so that a man could occasionally get in his arm, to clear away any chips, sand, dirt, or other matter which might have accumulated. Representations of this pump, and of all its detached parts, are given in the volume of Smeaton's *Reports* above referred to.

(357.) Another description of hand pump, by Mr. Noble, is very ingenious, but rather too complicated for sea purposes to be a general favourite with seamen. Here are two buckets, working one below the other in the same barrel, which rise and fall alternately, by having the rod of the lower of the two buckets pass down through the upper bucket in a collar of leather, and uniting the rods of the two buckets to the brake or lever on opposite sides of its centre, so that the descent of one causes the elevation of the other, and produce by their joint action a constant stream of water, one bucket being always raising a column while the other is descending for a fresh supply. Such a pump requires no lower valve, unless by way of precaution, in case either bucket should be out of repair, in which case it would become a single pump.

(358.) *Kingston's ship pump*.—This Machine is applicable as well to extinguishing fires on board, as for the usual purposes of pumping: it is commonly called a chest pump, being enclosed in a close case with handles, H H, fig. 5, pl. xxviii. for lifting it from place to place; the handles, when not in use, fall down vertically, occupying thus less room. Two brass cylinders, of four inches bore, are united by proper screws, nuts, and flanches, with the base B, in which is a pipe B communicating with each cylinder. The space around and between the cylinders and the casing of the pump serves as an air chamber, by which the water is kept under compression. The lower connecting pipe B is made to communicate with the supply of water by means of a leathern hose screwed on, at right angles to this section, unto the screw cut on the interior of the tube B, seen in fig. 6, and the eduction pipe is screwed on exteriorly upon the pipe C, fig. 6. The pistons are solid, and the action is obviously that of forcing. In the position of the rods, pistons, &c. shown in the drawing, the piston P has arrived at the top of its stroke, the water following it through the open valve V, while the descent of the other piston P' has forced its water through the valve V'' into the air chamber. On the return stroke the valve V will be shut, and the valve V' will be forced open, while the water in this barrel is being forced into the air vessel. During this the piston P' is elevated, and the water from the communicating pipe B forces open the valve V'', while V' is kept shut by the pressure of the air and water in the chest E. In the mean time the water is thrown out in a continued stream through the eduction pipe when used for common pumping, or

Noble's
ship pump

Kingston's
ship pump.

Manufactures.

through the flexible hose and pipe when used for the purpose of extinguishing a fire. The parallel action of the piston rods is obtained in nearly the same way as in the steam engine, by means of the bridle links I I' connecting the hanging links L L' with the standards G G': the piston acting on a joint in the centre of the hanging links. The brake or handle by which the pistons are worked turns on an axle, supported by the central strong standard F F', which is fixed in its place by being screwed into the base, and passing through a hole in the upper part of the air chamber. Through a hole at the end of the iron handles is fixed a transverse bar, so as to allow as many men to work on each side as may be thought necessary. As the drawing sufficiently illustrates the entire operation of this very simple apparatus, we need only add that the whole is securely screwed down to a wooden frame D D, which serves as a base; the screws by which this is effected being seen in fig. 6, but not in the section, fig. 5.

Jekyl's pump.

(359.) Another pump, which seems to have been considered a very good one, was invented by Capt. Jekyl, R. N., and several of them were introduced into the British Navy; but for some reason they are now seldom applied. Beside this we might enumerate many others, but as they are seldom if ever used, it would be to little advantage to the reader. It may also be observed, that besides the different arrangements above alluded to in the pumps themselves, different methods of working them have also been suggested, by converting the reciprocating motion of the handle into a circular motion, and by converting the up and down motion of the handle into a motion resembling that of rowing, in which a man is generally considered to exert his strength to the best advantage, and particularly a sailor, who is familiar with the rowing motion.

We shall conclude this division by describing the common ship pump and chain pump now generally adopted in the British Navy.

Common ship pump.

(360.) Both of these are remarkably simple. The sucking and lifting pump differs scarcely at all from the common lifting pump, except in the form of its handle, which has a transverse bar for the convenience of employing more than one man. The barrel in which the piston works is three feet long, composed of brass, accurately bored to five inches. The upper part of the piston rod also differs a little from a common pump, by working through a collar of leather, whereby a certain degree of compression may be given to the water, so as to allow of its being worked as a fire engine; when thus employed, a part is added to the common pipe, and held fast on by a clasp hook on each side. On the exterior part is an exterior screw, on which may be screwed the leathern hose when the pump is used for projecting the water to any distance; as in the case of fire, or for any other purpose.

Chain pump. Pl. xxviii. Fig. 8.

(361.) *Chain pump for ships.*—The chain pump, fig. 8, is only a long chain A, with a sufficient number of pistons, called buckets or saucers, fixed upon it at proper distances; it passes downwards through a wooden tube B, and returns upwards in the same manner, on the other side D, the ends being united together. The chain is extended over two wheels E and F, called sprocket wheels; one is placed over the tubes B and C of the pump, and the other at the bottom in the space between the two tubes through which the chain ascends and descends. By turning the upper

wheel E, the chain of buckets is put in motion, and the lower part of the wooden tube in which the chain ascends is lined with a brass barrel, in which the saucers are fitted, and as they continually ascend they raise the water, which runs off from the top of the ascending trunk, and is carried by a trunk through the ship's side into the sea. The pump is worked by a crank or winch G, fixed on the axis of the upper wheel, whereon several men may be employed at once; and thus it discharges, in a limited time, a much greater quantity of water than the common pump, and with less inconvenience to the labourers.

Machinery

The chain pump now in use in the Navy is of a very improved construction, compared with the original chain pump. It was introduced by Mr. Cole, under the direction of Captain Bentinck; its chain is very simple, and not much exposed to damage; being exactly similar to that of the fire engine, and appears to have been first applied to the pump by Mr. Mylne to exhaust the water from the caissons at Blackfriars bridge. It has thence been transferred to the marine by Captain Bentinck, after having received some material additions to fit it for that service.

The links of the chain are each formed of two long plates of iron *ee*, with a hole at each end, and fixed together by two bolts, serving as pins for the joints. The buckets or saucers fixed upon it are two circular plates of brass *g*, with a piece of leather between them. The sprocket wheels for the chain are formed in the same manner as the trundles used in mills, by two iron wheels fixed at eight inches' distance upon their axles, and united by several round iron bolts, forming a rest for the chain; and its links have hooks *b*, which are taken by these bolts, and thus the chain is secured upon the wheel, to prevent it from jerking back when charged with a column of water.

This, as above stated, is a great improvement upon the old chain pump, in which the chain was complicated, and the sprocket wheels used to work it were deficient in wanting some contrivance to prevent the chain from sliding or jerking back upon the surface of the wheel, which frequently happened when the buckets were charged with a considerable weight of water, or when the pumps were violently worked; the links also were too short, and the manner in which they were connected, exposed them to great friction in passing round the wheels; hence they were sometimes apt to break or burst asunder in very dangerous situations, when it was extremely difficult or impracticable to repair the chain.

The present pump is so constructed that the chain may be easily taken up and repaired when broken or choked with ballast; and it discharges a much greater quantity of water with an inferior number of men, as appeared from a trial with it and the old chain pump aboard the Seaford frigate, where it was found that its effects, when compared with the latter, were as follows: the new pump with four men raised one ton of water in forty-three seconds and a half, while the old pump required seven men to raise the same quantity of water in seventy-six seconds.

In this experiment the chain of the new pump was purposely broken and dropped into the well, and afterwards taken up and repaired, and set to work again in two minutes and a half; then the lower wheel of the pump was taken out, to show how readily it might be cleared and refitted for action, after being choked with sand or gravel, which could be performed in four or

Manufac-
tures.

five minutes. These are advantages of equal importance with that of increasing the quantity of water which the Machine will raise.

The only alteration which has been made in this pump since its first introduction is, that the lower sprocket wheel is now omitted altogether, the ascending and descending pipes being so united by a curved metal tube, that the chain passes better than if a wheel were used. The cranks are made to take off and to be applied when wanted, that they may not be in the way; they are long enough for thirty men to work at once: of late it has been proposed to add fly wheels to them. This would be attended with but slight advantage while it would introduce several inconveniences, from occupying that room where the men should stand to work, it being an object to employ as many as possible; but if they are crowded, they only incommode each other instead of assisting.

Fire Engine.

Early his-
tory of the
fire engine.

(362.) The invention of the fire engine appears to be nearly coeval with that of the pump, both being attributed to Ctesibius, who lived in Egypt in the time of Ptolemy Philadelphus and Ptolemy Euergetes; at all events, Hero, who was a pupil of Ctesibius, expressly describes a forcing pump with two cylinders as a Machine applicable to the purpose of extinguishing fires, but it does not appear that it was very generally adopted. That the fire engine was known, although, perhaps, not very generally made use of by the Romans, appears by a letter from Pliny to the Emperor Trajan, in which he announces the destruction of the town of Nicomedia, in Bithynia, by fire, remarking, that the devastation had been increased by a violent storm which took place at the time, by the laziness of the inhabitants, and by the want of Machines or apparatus proper for extinguishing the flames. These Machines are referred to by Pliny under the term *sipho*, which some have maintained means only water pipes; but Beckmann seems to have no doubt that *sipho*, in this place, must have meant a fire engine, and quotes a passage from a fragment of a Work of Apollodorus, the architect to Trajan, which seems decisive of the question: this quotation relates to a method of extinguishing a fire in the upper part of a house when the *sipho* is not at hand, which consisted of filling leathern bags with water, and connecting long pipes to them, so that by compressing the bags the water might be projected to certain heights. However rude this contrivance may be, it shows clearly that, being intended to supply the place of the *sipho*, this latter could have been nothing less than some kind of fire engine. There are, however, strong reasons, from other circumstances, for concluding, that although the fire engine was not unknown to the Romans, it was very little employed, and was most likely invented in much more recent times in Germany without any knowledge of the Roman engine, but at what time it was first introduced into that Country is by no means certain. It is remarked by Von Stetten, that in the building accounts of the city of Augsburg fire engines are first mentioned in the year 1518. They are called there *instruments for fires*, or *water syringes* used at fires; and these names seem to announce that the Machine was then in its infancy. At that time, they were made by a goldsmith at Friedberg, named Anthony Blanter, who, the same year, became citizen of Augs-

burg. From the account added, that the wheels and levers were constructed by a wheelwright, and from the greatness of the expense, there is reason to conclude that these were not small, simple hand engines, but large and complex Machines. Machinery.

In the year 1657, the celebrated Jesuit, Caspar Schott, was struck with admiration on seeing at Nuremberg a fire engine, which had been made there by John Hantsch. It stood on a sledge ten feet long and four feet broad. The water cistern was eight feet in length, four in height, and two in width. It was moved by twenty-eight men, and forced a stream of water an inch in diameter to the height of eighty feet, consequently over the houses. The Machine was drawn by two horses. Hantsch distributed throughout Germany an engraving of it, with an offer of constructing similar ones at a moderate price, and teaching the use of them; but he refused to show the internal construction of it to Schott, who, however, readily conjectured it. From what he says of it, one may easily perceive that the cylinders did not stand in a perpendicular direction, but lay horizontally in a box, so that the pistons moved horizontally and not vertically, as at present. Upright cylinders, therefore, seem to belong to the more modern improvements. Schott adds that this was not a new invention, as there were such engines in other towns, and he himself, forty years before, and consequently in 1617, had seen one, but much smaller, at Königshofen, his native city. George Hantsch, also, son of the above artist, constructed similar engines, perhaps with improvements, for Wagenseil and others have ascribed to him the invention.

The first regulations at Paris respecting fires, as far as is known, were made to restrain incendiaries, who, in the XIVth Century, under the name of *boutefoux*, occasioned great devastation not only in the Capital but in the Provinces. Paris appears to have obtained fire engines, for the first time, in the year 1699; at any rate the King at that period gave an exclusive right to Dumourier Duperrier to construct those Machines called *pompes portatives*; and he was engaged, at a certain salary, to keep in repair seventeen of them, purchased for the city, and to procure and to pay the necessary workmen. In the year 1722, the number of these engines was increased to thirty, which were distributed in different quarters of the city, and at that time the contractors received annually twenty thousand livres.

In the middle of the XVIIth Century, fire engines were still very imperfect. They had neither an air chamber nor buckets, and required a great many men to work them. They consisted merely of a sucking pump and forcing pump united, which projected the water only in spurts, and with continual interruption. Such Machines, on each movement of the lever, experience a stoppage, during which no water is thrown out; and because the pipe is fixed, it cannot convey water to remote places, though it may reach a fire at no great distance, where there are doors and windows to afford a passage. At the same time the firemen are exposed to danger from the falling of the houses on fire, and must remove from them to a greater distance. Hantsch, however, had adapted to his engine a flexible pipe, which could be turned to any side as might be necessary, but certainly not an air chamber, otherwise Schott would have mentioned it. In the time of Belidor there were no other engines in France, and the same kind alone were used in England in 1760.

Manufactures.

Who first conceived the idea of applying to the fire engine an air chamber, in which the included air, by compressing the water, forces it out in a continued stream, is not known. According to a conjecture of Perrault, Vitruvius seems to speak of a similar construction; but Perrault himself acknowledges that the obscure passage in question might be explained in another manner. The air chamber in its action has a similarity to Hero's fountain, in which the air compressed by the water obliges the latter to ascend.

We find no older fire engine constructed with an air chamber than that of which Perrault has given a figure and description. He says it was kept in the King's Library at Paris, and during fires could project water to a great height, that it had only one cylinder, and yet threw out the water in one continued jet. He mentions neither its age nor the inventor; his book was printed in 1684. The principle of this Machine, however, seems to have been mentioned before by Marriotte, who, on this account, is by some considered as the inventor; but he does not appear to have had any idea of a fire engine, at least he does not mention it.

It is certain that the air chamber, at least in Germany, did not come into common use till after it was applied by Leupold to fire engines, a great number of which he manufactured and sold. He gave an account of it in a small Work, consisting of four sheets quarto, which was published in 1720, but at first he kept the construction a secret. The engines which he sold consisted of a strong copper box closely shut and well soldered. They weighed no more than sixteen pounds, occupied little room, and only one cylinder, and a man with one of them could force up the water without interruption to the height of from twenty to thirty feet. About 1725, Du Fay saw one of Leupold's engines at Strasburg, and discovered, by conjecture, the construction of it, which he made known in the *Transactions of the Academy of Sciences, at Paris*, for that year. It is very singular that, on this occasion, Du Fay says nothing of Marriotte, or of the engine in the King's Library. Leupold, however, had some time before, that is in 1724, given a description and figure in his *Theatrum Machinarum Hydraulicarum*, with which, undoubtedly, Du Fay was not acquainted.

Another improvement, no less useful, is the leathern hose added to the engine, which can be lengthened or shortened as necessary, and to which the fire pipe is applied, so that the person who directs the jet of water can approach the fire with less danger. This invention, it is well known, belongs to two Dutchmen, both named Jan Van der Heide, who were inspectors of the apparatus for extinguishing fires at Amsterdam. The first public experiments made with it took place in 1672, and were attended with so much success, that, at a fire next year, the old engines were used for the last time, the new ones being introduced in their stead. In 1677, the inventor obtained an exclusive privilege to make these engines during the period of twenty-five years. In 1682, engines on this construction were distributed in sufficient number throughout the whole city, and the old ones were entirely laid aside. In 1695, there were in Amsterdam sixty of these engines, the nearest six of which were to be employed at every fire; and in the course of a few years they were common throughout all the towns in the Netherlands.

All these circumstances have been related by the inventor in a particular Work, which, on account of the

excellent engravings it contains, is exceedingly valuable. Machinery Of these, the first seven represented dangerous conflagrations at which the old engines were used, but produced very little effect. One of them is the fire which took place in the Stadthouse of Amsterdam in the year 1652. The twelve following plates represent fires which were extinguished by means of the new engines, and exhibit, at the same time, the various ways in which the engines may be employed with advantage. According to an annexed calculation, the city of Amsterdam lost by ten fires, when the old apparatus was in use, 1,024,130 florins; but in the following five years, after the introduction of the new engines, the loss occasioned by forty fires amounted only to 18,355 florins; so that the yearly saving was ninety-eight per cent. Of the internal construction of these engines no description or plates have been given, nor is there any reason to believe they were furnished with an air chamber, though in the patents they were always called *spouting-engines* which threw up one continued jet of water. The account given even of the nature of the pipe or hose is short and defective, probably with a view to render it more difficult to be imitated. It is only said that it was made of leather in a particular manner, and that besides being thick, it was capable of resisting the force of the water. The conducting or feeding hose was also the invention of the same two Dutchmen, the end intended to be placed in the pond or river having been by them inserted in a cork to float it, and its end was defended by a grating or brass plate pierced with small holes to prevent any mud or dirt from entering.

Here then, with the exception of the air vessel, is the completion of the invention of the fire engine, viz. a sucking and forcing pump, some method to preserve a constant stream of water, flexible hose for bringing water from any approachable supply, and a directing pipe furnished also with flexible hose for conducting the jet of water into narrow places into which the engine itself could not be taken. The modern fire engine in principle is no more than this with the addition of an air vessel, but the progress of the Arts has of course added much to the perfection and performance of it in other respects as compared with those of the old construction, and the forms it has undergone have been proportionally numerous. Notwithstanding hose were undoubtedly known on the Continent many years before they were used in England, they were always more or less defective; some were made of canvass covered with a cement to make them water tight, some were woven in the tubular form by looms or Machines made expressly for the purpose, and others were made of leather, which is the material now commonly employed in this Country; and as preserving them always water tight is a matter of some difficulty, several ingenious persons have directed their attention to this object.

One of the most recent improvements in their construction is due to Mr. Perkins, so well known for his many ingenious inventions. The usual method of closing the two edges of the leather to form the hose, was by sewing them together as a shoemaker closes the leather of a pair of boots, but Mr. Perkins recommends that instead of sewing them, the sides should be closed with rivets, indeed the rivet had been before employed for this purpose by Messrs. Hancock and Sellers of Philadelphia, for several years; but Mr. Perkins's operates somewhat differently. He recommends that the leather should be more overlapped, and has invented a method of connecting two

Manufac-
tures.

hose without contracting the water way at the joints. Particulars relative to this improvement will be found in vol. xxxviii. of the *Transactions of the Society for the Encouragement of Arts, &c.* It will be sufficient for us here to give a verbal description of it. The rivets substituted for the usual thread are of copper, and the overlapping of the leather serves when it is wetted as a sort of valve to tighten the seam; and as the portion of the hose next to the engine is found to be the part which most commonly bursts, especially when the water is carried perpendicularly, the first three or four portions are double rivetted, the other part has only a single row, and the different pieces of leather that compose the hose in length are connected by a double spiral joining of double rivets.

It is not, however, in this part that the greatest improvements have been introduced, but in the pump gear, in the air vessels, and in the whole structure of the Machine, which is now made with all the care and accuracy the important duty of the engine requires, and which only modern workmanship could supply.

It appears that the first double acting fire engine with an air chamber or air vessel, in England, was made by Mr. Newman, an engine maker in London, about the middle of the last century, and is therefore commonly known by the name of Newman's fire engine; although there seems to be no particular claim for its being thus distinguished, as we have seen the principle of this kind of engine was well known on the Continent before his time; it is probable, however, that he gave it its more modern and convenient form.

Modern fire
engine.
Pl. xxix.

(363.) A fire engine of this kind acting under a spring of compressed air is represented in plate xxix. This engine is now very differently formed by different makers, but the principle of action is nearly the same in all. **A B**, fig. 1, is a cistern about nine feet long and three broad, or in nearly these proportions. It is mounted on wheels, to which are attached shafts, whereby to draw it with horses, or a simple pole and cross handle, when only intended to be moved by men; the cistern is commonly made of strong oak planks, with the joints well secured by copper plates to prevent it from leaking. The hind axletree on which the two opposite hind wheels turn is a fixture to the bottom of the cistern; but the fore axletree, borne by the fore wheels, is put on a strong pin or bolt, fastened in the middle of the front of the bottom of the cistern, by which means the two fore wheels and the axletree have a circular motion, whereby the engine may be more conveniently turned round a corner, and be made to stand firm on a sloping plane. At the back part of the engine is a brass tubular projection with an external screw, and the companion screw is fixed to a long leathern pipe; this being attached to the part on the engine, the other end is carried to any river, pond, or ditch, from which water may be obtained, and thus furnishes a feeding or sucking pipe to the cistern; but when such source of water is not to be obtained, it is brought by hand in buckets, or rather according to the well-known process at fires, the buckets are handed along by a row of persons and emptied successively into the small trough at the end of the cistern seen in the figure at **G**; between which and the cistern is a fine copper grating to prevent any mud or dirt entering the latter, which would have an injurious effect upon the valves and pistons of the pumps. A similar trough is also placed at the front of the cistern, and furnished in the same way with a proper copper grating.

The pumps are worked by a number of persons seizing the long side rods seen in the figure, and frequently these are assisted by other persons standing on treadles inside the upper framing by their throwing their weight alternately from side to side, keeping themselves steady by means of two horizontal rails framed into four vertical stands which reach to the bottom of the cistern and are well secured to its sides. Over the hind trough there is an iron handle or key **K** serving to open or shut a cock placed under it on the bottom of the cistern. **L** is an inverted pyramidal box or case which preserves the pumps and air vessels from damage, and also supports a wooden frame or platform on which a man may stand to direct the current of projected water, either by raising or depressing it, or guiding it from side to side as occasion may require; the bottom part of the pipe being allowed this freedom of motion by being there formed of two pieces of brass pipe, each of which has an elbow. The lower end of this is screwed to a pipe which descends through the air vessel to the water, and to the upper part is screwed, by a well-fitted screw, the pipe or hose, so as to render it water tight in every position. The conical form of the directing pipe serves to contract the stream of water, and thereby to increase its velocity of projection; while the valves and leathern pipes of the engine have sufficient water way to supply the jet in its greatest velocity. Sometimes when the engine cannot be got sufficiently near to the place where the fire rages to have the water directed upon it from the pipe seen in the figure, a long flexible leathern hose may be screwed on in its place, and the pipe itself screwed to the other end; by this means the water may be carried inside the house on fire, or into narrow courts and alleys where the engine itself cannot be taken. Between the wooden case **L** and the fore end of the engine, there is a strong iron bar **O** lying in a horizontal position over the middle of the cistern, and playing in brasses supported by two wooden stands, one of which is placed before the fore stands of the upper rails, and the other within the box or case **L**. Upon proper squares of this bar are fitted, one near each end, two strong cross bars, and to these are fixed the two long cylindrical handles by means of which the engine is worked. The method of working the pumps is seen on an enlarged scale in fig. 2. **A B C D** is a double sector of iron, having sufficient breadth of sole to receive two chains resembling a clock chain; one end of one chain is fastened to the bottom of the arch head, and to the top of the piston rod, and the other chain is fixed at one end to the top of the arch head and the lower part of the piston rod, whereby, when the sector descends on one side, the chain fixed at its lower part winds round and pulls down the piston on that side, while in the opposite sector the chain fixed on the upper part of its arch head winds round and raises the other piston; the reverse takes place the next stroke, and thus a continual action is carried on, the pump acting by suction during the ascent of the piston, and by forcing during its descent. While either piston is ascending, the water rushes through the lower valve from the cistern and fills the cylinder, and when the piston descends this valve shuts by the pressure of the water, and is forced through the valve, seen in fig. 3, into the air vessel, the upper part of which is filled with air compressed by thus forcing the water in, and which thus acting by its elasticity on the surface of the water, causes it to be projected with velocities and to heights greater or less according to the degree to which the air

Machinery

Manufactures.

is compressed. The treadles for working the engine by men placed above the cistern are suspended from the hind arched heads above described, which work the pumps, and from a similar but smaller double sector, (having only to support the treadles,) seen at Q. The ends of the treadles at the hind part pass through openings in the piston rods, seen at H, G, fig. 2. The hind sectors are also seen in fig. 3, with the treadles passing through the opening as above described. This figure represents a section through the middle line of the hinder part of the engine, and also a section of the air vessel, and that of one of the barrels or cylinders, as likewise the elevation of the hind sectors and other parts. A B is the section of the bottom of the cistern, and C that of the hind axletree. D E is the vertical section of a strong piece of cast brass, iron or other hard metal, so worked as to have a hollow in it, and fixed to the bottom of the cistern. This reaches from the opening D to the cock W, and afterwards divides itself into two branches, so as to open under each barrel, but only one of these branches can be seen in the figure, the other being behind. Through this channel the water is conveyed to the pumps by the pressure of the atmosphere, either from the cistern itself or from any place at a distance, by means of the leathern feeding pipe which screws on to a projecting short tube D, under the hind trough Z, fig. 3, or under the trough G, fig. 1. F G, fig. 3, represents the vertical section of another piece of cast brass which may be called the communicating piece, having two hollows for conveying the water from under the two pistons to the two openings of the flanch of the air vessel, one only of which is seen in the figure; the other lies behind this, although not in a parallel direction. Between the section of the sucking piece D E, and that of the communicating piece F G, is seen the section of one of the plates of leather which makes all tight, and forms one of the two sucking valves, of which there is another just behind under the other barrel. R S T is the section of the copper air vessel, and I V that of the conducting pipe; this vessel is screwed on to the hind part of the communicating piece, and at the top is fastened by a collar of iron to a cross piece of timber. Between the flanch of the air vessel and the communicating piece is shown the section of one of the leather plates making all tight, and securing one of the two forcing valves, of which there is of course a similar one in the other opening not shown. These valves are loaded with a weight of iron or lead, having a tail let through the flap of the valve and cross pinner under it. It may be proper to observe, that from the nature of the operation when the water presses to open the valve in the air vessel, that which opens to the cistern is shut, and on the return stroke, when the lower valve is opened by the upward pressure of the water from the cistern, that in the air vessel is shut by the pressure of the air in the vessel, so that these valves can never be both open at the same time.

H I is a section of one of the pump barrels, which are both sucking and forcing, as appears from the position of the valves and the structure of the piston, each of which is composed of two iron plates, of two wooden plates, and of two flat pieces of leather, turned one up and the other down. L K represents one of the piston rods, seen edgewise, behind which is one of the chains, the upper screw of which, K, can only be seen. M is the end of the middle bar, and N a section of the hindmost of the two middle stands which support the middle bar,

and O represents the end of the profile of one of the treadles passing through the rectangular opening in the piston rod, as shown at H G in fig. 2. Machinery.

In fig. 3, X Y represents an iron handle by means of which the cock W may be set in any required direction; viz. either so as to make a communication between the cistern and barrels, or between the feeding pipe and barrels shutting off the cistern, according to the means by which the engine is supplied.

The principle of action is sufficiently obvious, the air being compressed in the air vessel by forcing in the water to (let us suppose) half its original bulk. The water will be pressed internally by the amount of two atmospheres, and outside with only one, consequently the internal pressure would sustain an external column of water thirty-three feet high; and to this height the water will be projected, except some small diminution arising from the friction of the water along the pipe and the resistance of the atmosphere. If the air be further compressed by an additional quantity of water to one-half its last bulk, or to one-third its original bulk, there will be the pressure of three atmospheres internally to one externally, and the internal pressure would support a column sixty-six feet high, to which height the water may now be thrown, and so on for greater or less pressures; a force, however, internally of three atmospheres is generally amply sufficient for most cases. The engine above described is one of the most simple of the kind. It has been stated that they are now made of various sizes and forms, and some with double force pumps; the general principle, however, is the same, and the above description will be therefore sufficient.

(364.) *Local fire engines.*—The fire engine above described may be distinguished as a locomotive engine, readily removed from place to place, either by the aid of men or horses; but of late years it is not unusual in large establishments to have local engines which are immovable from the situation in which they are placed. In the Royal Arsenal at Woolwich a substitute for an engine of this description is furnished by a permanent reservoir about seventy-eight feet above the arsenal. The pressure of the water from this natural head supplies, of course, a power equivalent to such a column, and in case of any accident in which its aid is required, the simple turning of a cock supplies at once not only the water, but a pressure sufficient to carry the stream over the highest buildings; an object of great importance in an establishment where so many valuable stores are deposited, and where so many combustible and explosive materials are deposited. Local fire engine.

In his Majesty's Dock-yard at Chatham, this object is attained by the construction of a powerful forcing engine placed under the level of the yard, and which is worked by eighty men at capstan bars; the vertical shaft connected with the head of the capstan is supported on a proper bearing about six feet below the ground surface, and a little above its bearing is furnished with a large horizontal bevelled wheel which acts upon a smaller bevelled wheel placed vertically on a strong horizontal shaft, supported by proper bearings, and having three cranks upon it placed at angles of 120° with each other. These cranks work pump rods which descend to three pump barrels of eight inches bore, and which force on the ascending stroke. All these barrels communicate with one large and strong cast iron air vessel in which the air is kept in a high state of compression, and forces the water along a main pipe, which may be opened by

Manufac-
tures.

proper plugs at almost any part of this great establishment where its service is at all likely to be required.

The late Sir William Congreve also was the projector of local fire engines of a different kind, but we believe they have been but little adopted. His plan consisted in placing a large reservoir of water on the top of any building of great magnitude or importance, such as Government or Mercantile storehouses, warehouses, &c., as also Playhouses, and places of public amusement; from this reservoir descended pipes to those parts of the building where accidents were most likely to occur, or which it might be considered of the greatest importance to protect, so that the moment an accident occurred the means were at hand to check the progress of the flames; and indulging his imagination, some of these pipes were furnished with adjutages which revolved with the force of the water issuing from them, and thus cast it about the building in all directions. A model of a design of this kind, intended for Drury Lane theatre, was for several years exhibited in the Repository at Woolwich, the action and operation of which displayed great ingenuity.

The importance of the fire engine in every town cannot but be fully admitted; but of all towns or cities, the metropolis of this Country, the most populous in Europe, stands more in need of this Machine than any other, and is accordingly much better provided with them, many of them of the most powerful description; their places of deposit are well known, and premiums are paid to the earliest engines that arrive. Another convenience is provided in London, and in most large towns artificially supplied with water, *i. e.* proper water plugs, which may be generally opened on the spot, to furnish the requisite supply of water for the use of the engine; and various ingenious contrivances have been employed to add to these, a Machine of general application, called a Fire-escape, for saving the lives of persons and valuable property from the upper part of a house which is already so much enveloped in flames as to prevent any interior communication.

Various Machines of this kind have been proposed, of which several are described in the *Transactions of the Society of Arts*, and from which we select the one given below. This is taken from vol. xxviii.; others may be seen by consulting vols. xxxi., xxxiv., and xxxix.

Fire-escape. (365.) *Fire-escape by Mr. Davies.*—This is meant to be a Parish Machine, kept, as the fire engine is, always in repair, and always ready to be applied on the first alarm. It consists of three ladders applied to each other by four clasp irons on the top of each of the two lowermost, which are so contrived that each ladder may slide into the one beneath it; on the top of the lowermost ladder two pulleys are fixed on the inside, over which two ropes pass, and are situated between the lower ladder and the middle one. The ropes are made fast to the bottom of the middle one on each side in a proper direction with the pulleys on the top. The upper ladder is attached to the middle one in the same manner, and on the top it carries two horn pieces made of iron, and turned off at each end similar to two horns, which are four feet wide; their ends are sharp, to pitch on each side of a window, and with its points hold the ladder steady. The three ladders when shut down are fifteen feet in height. They are placed perpendicular in the middle of a framed carriage of nine feet six inches long, and five feet six inches wide, mounted upon four wheels. On each side of the carriage a windlass is placed, to which ropes are attached,

and also to the bottom ladders; these are passed over pulleys, so that by turning this windlass the ladders may be wound out from their standing height of fifteen feet to forty-five. Over this windlass is a screw turned by a winch, by turning which the ladders may be inclined against the house with all imaginable ease. On the top of the upper ladder, on the outside, are two pulleys, over which two chains are conducted to the windlass on one side for the purpose of carrying up a box, two of which travel with the fire-escape; so that in the event of one being filled with small valuables it may be unhooked, and the other put on, which will save time. The whole apparatus may be drawn by one horse or six men, and when arrived at the scene of danger, may be adjusted in a few minutes. *Society of Arts*, vol. xxviii.

(366.) *Garden engine.*—This is very similar in its construction to the old fire engine, but is of course on a much smaller scale, is made generally to be worked by a single handle, and is seldom supplied with an air vessel. The larger sort is mounted on wheels which are attached to the cistern, others are supported by a single wheel and two front feet like a wheelbarrow; others again are detached from the cistern, being in fact little more than a portable forcing pump, intended to be worked in buckets of water. These kind of engines, however, are too common and of too trivial a character to require further description in this place.

(367.) *Pile engine* is a term usually applied to a simple but very useful Machine employed a great deal in Hydraulic Architecture, and frequently also in other cases; but in the construction of bridges, wharfs, docks, basins, &c., it is indispensable, and some ingenuity has been exercised in giving it the most convenient form. The object of this engine is the driving of piles for forming the sides of quay walls, and for carrying the sleepers for the foundation of heavy buildings of all kinds where the soil itself has not sufficient solidity to afford a proper resistance to the weight of the erection.

Without attempting a description of the Pile engines commonly given in our Works on Mechanics, which are now very rarely if ever employed, it is proposed to explain one of the most simple kind as it is now commonly made. This (represented in plate xxix.) consists first of a base formed by four timbers crossing each other at right angles, and bolted together, and to the two cross timbers is bolted a crab, with a barrel and two handles (not shown.) This is worked by four or more men. Between the cross timbers at A and B, fig. 5, are erected two upright pieces of timber defended by thin plates of iron, on the other side is a ladder sloping towards the top for the convenience of ascending, and the whole is then securely braced in an erect position by the side props seen in fig. 5 and 6; a wheel or large pulley is fixed at top, over which a rope or chain passes; one end of this is fixed to the barrel of the crab, and the other to a part called the monkey: this piece is shown in fig. 7. The monkey has a front and back plate, the latter of which, being removed, allows the other part to pass between the upright slides; the back plate is then screwed on and the nuts so adjusted as to enable the monkey to slide freely up and down the slides of the Machine. The rope is attached at H, and below, as at G, the nippers shown in fig. 8 are suspended from their axes. These take hold of the handle or ear on the ram W, fig. 9, the weight of which, as well as their form, preserve them shut, and the ram having a back plate the same as the monkey, is prevented from rebounding

Machinery.

Garden engine.

Pile engine. Pl. xxix.

Manufactures.

away when it falls. The method of relieving the ram so as to give it a free descent, is as follows:—On the upper part of the slides, fig. 5, are seen two inclined planes K L; and it will readily be perceived that when the monkey has been raised so high that the bowed handles of fig. 8 enter between them, these will be compressed by the same force that raises the weight, and by their closing, the bottom part of the nippers will open and the ear of the ram will escape between the lower jaws, and fall with its entire momentum upon the top of the pile. The weight of the ram is commonly ten hundred weight. This being now below, the weight of the monkey and nippers together is sufficient to cause these to descend by their own gravity; they thus come again in contact with the ear of the ram, and their shape is such that they will open by the pressure and admit this ear as before, and close again so as to be ready to be once more lifted by the effort of the men at the crab. When arrived at the top, the inclined plane closes the handle of the nippers as before, and the ram again falls; the operation being thus repeated till the pile has been driven the proposed depth into the soil, which is sometimes a work of great time and of considerable labour. In order to defend the pile from splitting by the blows at top, it is encircled by a stout iron hoop, driven on to its upper part, while to facilitate its penetration, it is furnished at bottom with what is called an iron shoe, which is pointed, and gradually expands to the size of the pile, the latter being itself tapered by an adze.

Withdrawing piles.

The pile being driven, is sometimes to remain in its place, and frequently it is requisite to cut off the upper parts of a row of such piling under water to a straight line; (this is done by a Machine described under the article Saw-mill;) at others it is necessary, after the work for which the piles were driven is completed, to withdraw them again. This generally occurs in building stone or brick walls for quays; the piles being employed only to form a dam against the water during the erection of the wall. This operation is commonly effected in tide rivers and harbours by attaching barges to the pile at low water, and then, as the tide rises, the barge rises, and the pile must follow or pull the barge under water. Should the latter be probable, the barge must be made free, and a vessel of greater floating power employed. Bramah's hydrostatic press also has been sometimes employed for this purpose.

Questions respecting the proper height of pile engines.

(368.) The height to which the ram of a pile should be raised to produce the best effect, as regards the ultimate time of driving, is a question which can hardly ever become of practical importance, because the engineer is frequently limited in his means by other considerations than those of employing the least time; although, as a matter of economy, the latter point must not be wholly overlooked. The subject, however, some years ago, engaged the attention of several able scientific men. It is obvious that the higher the ram is lifted the longer time will be employed, not only in the operation of lifting, but also in the time of falling; but the blow will be greater also, and that in a higher ratio than the time; because the velocity is as the square root of the height, whereas the time is as the height merely: hence arose a question of maxima and minima, which led to great controversy; some making it appear that the effect would be greater the greater height, and others that it would be greater as the height was less. The parties engaged in this controversy were of some considerable scientific eminence; and it is rather to show

the fallacy of depending wholly on theory in practical cases, than for any other purpose, that we give the following remarks on this controversy, from the fourth volume of *The Collection of the Mathematical Papers from the Ladies' Diary*. Machinery.

It is easy to conceive that a pile may be driven so far into the ground that no power which it is possible to apply in the usual way can have an effect in producing any further motion in it. We are not, however, left to mere supposition and conjecture on this head, as this circumstance really occurred in driving the piles for the bridge of some mills, where the soil upon which the bridge was to be erected was pure sand of uniform density to the depth of 47 feet, yet no piles could be driven lower than 15 feet, although the rammers in the engines employed were enormously large.—Gregory's *Mechanics*, vol. i. p. 292. Hence it appears that it is possible to drive a pile so far that all future operations of the ram become wholly useless; yet there can be no doubt that if a sufficient momentum were applied, motion might be produced. Hence it follows, that whatever may have been said with regard to the incongruity of percussion and pressure, there is in reality a momentum which is precisely equivalent to the pressure and resistance of the pile; for since, as in the case we have mentioned, a momentum may be too small to produce any motion, while with a greater momentum motion will ensue, it follows that somewhere between the two a momentum may be found which is just sufficient to produce an equilibrium between itself and the resistance and pressure of the pile.

This circumstance, it is obvious, must always have place in all operations of this kind; that is, after the pile has been driven to a little depth the resistance will be such as to require a certain momentum to produce an equilibrium in the pile, and any momentum less than this will have no effect, however often repeated, in producing the required motion; and therefore if any greater momentum be applied, it is obviously only the difference between this, and that which is expended in putting the pile in equilibrium, that becomes effective, and which ought alone to be considered in computing the effect of the engine; and it is, doubtless, for want of duly attending to this circumstance that so many erroneous solutions have been given to this question. As to the momentum that may be necessary for producing the required equilibrium, it is obvious, from the various circumstances which may arise in the application of the pile engine, that this can only be determined by experiment, on some principle similar to the following. Suppose by experiment it is found that a momentum m drives the pile a inches; and a momentum M drives it b inches; and let it be required, hence, to determine the momentum y , which is equal to the resistance of the pile.

The first effective momentum is $m - y$, and the second $M - y$; and now admitting each effect proportional to its cause, we have $m - y : M - y :: a : b$, whence $b m - b y = a M - a y$, or $(a - b) y = a M - b m$, or $y = \frac{a M - b m}{a - b}$; which is the momentum equal to the resistance of the pile. Find the height due to this momentum, and call it h , then the solution of the problem will stand as follows:

Let x be the required height to produce the maximum,
 a the velocity per second in drawing up

2 q

Manufac-
tures.

t the time in falling,
 h the height necessary to produce the equilibrium,
 $g = 16 \frac{1}{2}$ feet,
 w the weight of the ram.

Then supposing the momentum to vary as the velocity, we have $2gt = v$; $vw = m$, the generated momentum,

$$\frac{x}{a} = \text{time in drawing up,}$$

$$\frac{\sqrt{x}}{\sqrt{g}} = \text{time in falling} = t,$$

$$\frac{x\sqrt{g} + a\sqrt{x}}{a\sqrt{g}} = \text{the whole time,}$$

$$2\sqrt{gx} = v, \text{ or } 2w\sqrt{gx} = m,$$

$$(\text{by substituting } \frac{\sqrt{x}}{\sqrt{g}} \text{ instead of } t.)$$

And h being the height due to the momentum above determined, this will be expressed by $2w\sqrt{gh}$, and consequently $2w\sqrt{gx} - 2w\sqrt{gh} = 2w(\sqrt{gx} - \sqrt{gh})$ is the effective momentum, which, divided by the time necessary for the production of it, must be a maximum; that is,

$$2w \frac{(\sqrt{gx} - \sqrt{gh})}{x\sqrt{g} + a\sqrt{x}} = \text{a max.,}$$

or

$$\frac{\sqrt{x} - \sqrt{h}}{x\sqrt{g} + a\sqrt{x}} = \text{a max.}$$

This, thrown into fluxions, gives

$$x \left\{ \frac{1}{2x} (x\sqrt{g} + a\sqrt{x}) - \sqrt{gx} + \sqrt{gh} \frac{x}{2\sqrt{x}} (\sqrt{x} - \sqrt{h}) \right\} = 0,$$

which reduced, gives

$$\frac{1}{2}\sqrt{gx} = \frac{1}{2}a\sqrt{\frac{h}{x}}\sqrt{gh},$$

or

$$x\sqrt{g} = a\sqrt{h} + 2\sqrt{gh}x,$$

or

$$x - 2\sqrt{hx} = a\sqrt{\frac{h}{g}};$$

whence

$$\sqrt{x} = \sqrt{h} \pm \sqrt{\left(h + a\sqrt{\frac{h}{g}}\right)},$$

or

$$x = \left\{ \sqrt{h} \pm \sqrt{\left(h + a\sqrt{\frac{h}{g}}\right)} \right\}^2,$$

the height required.

In the above solution has only been determined the height, when any single momentum, divided by the time necessary for the production of it, is a maximum; whereas the problem requires that the sum of all the momenta, divided by the whole time, should be a maximum. In order to determine this, we must assume a certain law of resistance, to which, applying the above principle of solution, a general result will be obtained. But as this assumed law of resistance must be totally supposititious, and probably very different from that which arises in practice, the preceding determination (supposing the value of h to have been found by experiment towards the conclusion of the operation of the engine) is probably more accurate than that which would result from the above supposition of a variable law of resistance. For it must be observed that x , as found above, is always the same function of h , that h increases as the blows are repeated, and consequently x also increases

each blow; but the distance between the top of the pile and the top of the engine also practically increases each stroke by the depth the pile has penetrated. It is therefore probable that the value of x found as above for any single stroke is very nearly, if not accurately, that which answers for the whole sum. We have already stated that this solution is not given so much with a view to real utility as with that of pointing out the necessity of attending to all the practical bearings of a question before we can hope to derive any assistance from theoretical investigations.

(369.) *Iron piling.*—Till very recently piles were always formed of timber, armed, as has been stated, at bottom by an iron shoe, and at top by a stout hoop or ring of iron; but, lately, Mr. R. Sibley, architect, of Great Ormond Street, suggested the piling with iron, and presented his plans for carrying these views into practice to the Institution of Civil Engineers, in which they led to considerable discussion, and excited, by the novelty of the idea, great attention. The first work of this kind was constructed, under the direction of Mr. Sibley, at the Island Lead Works, at Limehouse; a second work has since been executed by him, in forming a wharf at the South foot of the new London bridge; and another is now in progress on the opposite side.

In the wharf already constructed the piles are each in one casting, thirty feet long, and hollow throughout, chisel-pointed at the end, to facilitate their penetration into the soil, and in case there should be any stoppage to endanger the pile, or to cause it to take a wrong direction, a borer or jumper is used through the hollow of the pile. The piles are of a somewhat elliptical figure, with two pretty deep grooves one on each side. They are driven to their proper depth at distances of ten feet, and then iron plates of the same length, ten feet, are slipped down in these grooves, and form the facing of the wharf. Mr. Sibley, in a letter to the writer of this Essay, says, "The most eligible method to pursue in constructing a wharf on this principle is first to dredge the bed of the river to the intended depth, then to pitch and drive the piles, removing any impediment by the auger, or by jumping through the hollow of the pile, then to secure the piles by iron ties, fill in the plates, and back in the concrete."

The expense attending this method of forming a wharf is very inconsiderable when compared with that of erecting a stone face: the whole cost but little exceeding that of the coffer-dam necessary to be first constructed in such cases. The wharf at present constructing on this plan, at the North foot of London bridge, will be twelve feet above low-water mark.

Since this first suggestion by Mr. Sibley some deviation has been introduced into the practice by Mr. James Walker: an iron faced pier being now in course of construction at Blackwall, under the superintendence of Mr. George Bidder. In this the whole face of the pier is formed of piles, viz. main piles at every ten feet, and the intervals filled up with iron sheet piling, every other one overlapping two others, and supported at the top by one connecting piece, and by shoulders cast on the main piles. In this construction the question whether cast iron piles can be driven in hard soil has been put to a severe trial, a hard substance, known by the name of the Blackwall rock, lying a little below the bed of the river, having been penetrated, with but few accidents to the pile. In this work, however, the

Machinery

Iron piling.

**Manufac-
tures.** main piles are not all in one length, as in that above described, but formed in two, the hollow in the bottom part receiving a projecting end on the upper. The ram used in driving the piles weighs fifteen hundred weight, but its immediate blow on the head of the pile is intercepted by a piece of timber placed on the pile, which considerably relieves the jar, which would be most likely to injure the iron. We shall recur again to this subject in speaking of the construction of wharf walls, &c.

Miscellaneous Machines.

(370.) *Machine* is a very comprehensive term in practical Mechanics; we have seen that some Machines are denominated engines, others mills, &c. Those which retain the general denomination of Machines are also sometimes particularized by the nature of the processes in which they are employed; as Block-making Machines, Planing Machines, Blowing Machines, while others are designated according to their forms or objects, as cranes, jacks, locks, presses, &c. It is proposed in this section to give a description of the most general of these, arranged according to their alphabetical order; others which have only a particular application will be best described under the mechanical process or Manufacture in which they are exclusively employed.

**Block Ma-
chine.** *Block-making Machine.*—This denomination has been given to a very ingenious construction, consisting of numerous separate Machines worked by a steam engine in His Majesty's Dock-yard at Portsmouth, and of which a duplicate is also in store in Chatham Dock-yard. Before the year 1807, all blocks, as well for the Royal as for the Mercantile Navy, were formed by hand, although at that time different descriptions of saws were used, worked by Machinery, for the purpose of cutting and converting the timber into the sizes for the blocks; but the rest remained to be effected by hand; such as giving to the blocks their proper form, mortising, rivetting, &c. In the works we are about to describe, all these operations are performed by different Machines, constructed each for its individual purpose, and the whole in combination is, perhaps, one of the most interesting mechanical performances that can be well imagined.

The Machine, as it at present exists, is due to the inventive genius of Mr. M. J. Brunel, who has displayed as much judgment in the division of the operations by the several Machines, as ingenuity in the contrivance of their parts, which are admirably calculated to produce their intended effects. The greatest attention has been every where paid to that form of construction which would admit of the most perfect workmanship in the execution; and in this the ideas of the inventor were ably seconded by the late ingenious Mr. Henry Maudslay, who made the Machines with the most scrupulous attention to accuracy and durability, at the same time preserving that elegant proportion in their form for which the works of this engineer have always been so much distinguished.

Blocks are formed of elm, and the timbers are received at this mill in their rough state. These are first cut into short lengths proper to form the various blocks, by two large saws, one reciprocating and the other circular. The timber being thus reduced to planks of a proper thickness, is next cut into squares and ripped or split up into the proper sizes by four sawing benches with circular saws; there is also one very large reciprocating saw which is used for cutting up the pieces for

the larger blocks. The pieces being thus prepared are perforated by the three boring Machines, with a hole through each to contain the centre pin for the sheaves of the block, and as many other holes in a perpendicular direction to the former, as the number of sheaves it is to have, these holes being intended as the commencement of the several mortises to contain the sheaves.

The blocks are now mortised in three mortising engines, which elongate the holes above mentioned to their proper dimensions. The corners of the blocks are next cut off by three circular saws, preparatory to reducing them to the elliptical figure they are to have. The next process is to give them their outside figure by means of what are called shaping Machines, of which there are also the same number, three, each of which forms every part of ten blocks together. The scores or grooves are next formed round the block to receive the rope or strap by which they are to be suspended; this is done by two scoring Machines. The blocks now undergo the only manual operation to which they are submitted to smooth and polish them.

The block being thus far advanced, the next business is forming the sheaves. The first process here is cutting pieces of a proper thickness from the ends of trees of *lignum vitæ*. This is performed by what is called a converting Machine, of which there are also three; one consisting of a reciprocating saw, and the other two circular saws. These thicknesses, which already approximate towards the circular form, are cut circular and bored centrally at the same time by what are denominated trepanning or crown saws. A hole is now made in the centre of each sheave for receiving the coak or piece of bell metal which is fitted into the centre of each sheave to form a socket for the centre pin, and these being put in their places are rivetted fast by two rivetting hammers.

In some cases three small holes are drilled through each sheave and also passing through the coak, by the drilling Machine, and short wire pins, cut by the cutting shears, are put through these holes, and they are then rivetted down at the same time with the coak, by the rivetting hammer; but this is not always done, as the coaks are found to be firm enough without these pins or rivets.

The centre holes through the coaks are next broached out to a true cylinder in the three *broaching engines*. The last process is turning the faces and edges of the sheaves to a flat or rather to a slightly convex surface, in the three *facing lathes*, which also form the groove round the edges of them for the rope which encompasses them when in the block. This completes the Machines for making the sheaves. The iron pins are forged by two smiths in the usual manner of such articles, between two swages or tools, each having a semicylindrical cavity formed in it, so that the two when put together, form a cylinder. The heated iron being laid in one of these, the other is put over it, and beat with a hammer, by which means it forms the pin to a cylinder. The end of the pin is left square for a very short length. They are in this state turned smooth and true in the *pin turning lathe*, and afterwards polished and made perfect on the surface in the *polishing Machine*.

Such blocks as are from four to seven inches in length, are generally fitted with wooden pins, which are turned in a simple lathe. There are also two Machines for making *dead eyes*, and a large apparatus or boring

Manufac-
tures.

Machine for making the largest sizes of blocks, of that denomination called *made blocks*, some of which are as much as four feet in length, and with four sheaves. They are of course made up of planks, and this Machine is used for boring the holes of the numerous bolts which are used to unite these parts; it is also used for purposes unconnected with block making.

The number of Machines employed in these works is forty-three; the reader will therefore see that notwithstanding the great ingenuity displayed in them, it would be impossible for us to attempt a graphical illustration; nor is it indeed requisite that we should do so, because many of them, although possessing certain peculiarities to accommodate them to the purposes for which they are intended, do not differ essentially from other engines and Machinery described under their respective denominations in this Treatise. We shall endeavour, therefore, to give a verbal description sufficient for comprehending the general nature of the process as it relates to the application of Machines described in other parts of this Work, and shall attempt a graphic delineation of only one or two of those which are exclusively employed in the process of block making.

Different
kinds of
saws.

(371.) The saws, as we have seen, are of different kinds. One large reciprocating saw for cutting up the elm into planks of different thicknesses; for a description of which we may refer to the article Saw-mill, where also is described and delineated the revolving circular saw for cutting the *lignum vitæ* into flakes of the proper breadth or thickness for forming the sheaves. Besides these, there are several sawing benches with circular saws, which do not differ essentially from those described under the same article. The great reciprocating cross cutting saw may be readily comprehended. The tree subjected to the action of this Machine is placed on a long frame or bench raised a little from the floor, and at the end of it is erected a frame; through this the end of the tree is drawn by a capstan, its end projecting as much from the surface of the frame as is intended to be cut off; it is fastened in the frame, to prevent it rolling sideways, by a lever which can be easily made to press upon it and hold it down. The saw itself is a straight blade, fixed into a wooden handle or pole at each end. One of these handles is connected by a joint to the upper end of a lever bent like the letter L, and having its centre beneath the floor; the horizontal arm of the lever with a spear rod is worked with a crank on the end of a spindle near the ceiling, the motion of which is regulated by a fly wheel; this gives to the saw a reciprocating motion from right to left nearly in a horizontal position, and exactly across the log it is intended to cut off. In the commencement of its action the saw is guided in its vertical position by its back entering a saw kerf fixed in the frame, but as the operation of sawing proceeds the saw quits this saw kerf and is then guided by the cut already formed in the timber. The saw works by its own weight, but it may be lifted up at any time from its work by means of the handle which the attendant lifts and suspends by a rope when necessary; the saw will then continue its reciprocating action without cutting, being thus raised above its work.

Boring
Machine.

(372.) It has been already stated that after the elm is cut into the proper scantling, it is reduced to blocks of a proper size, square or rectangular, and that the next process is the boring. The boring Machine is a sort of compound lathe, having its mandrels placed at right angles to each other, to bore the blocks in these opposite

directions. These mandrels carry the boring tools which are pressed against the block secured in an iron frame which keeps it perfectly fixed and steady: on one side a central hole is bored for carrying the pin on which the sheaves are to turn, and on the other as many holes are formed as there are to be sheaves, each forming the commencement of the mortises in these directions, as already explained. This Machine is very ingeniously contrived, but it does not differ so far from what may be easily effected by a common lathe as to require a graphic delineation. The greatest difference is, that in common practice the block would be turned at right angles, elevated or depressed, and the holes bored by the same mandrel; whereas here two mandrels being used, placed exactly at right angles to each other, and at the requisite heights, the whole process is carried through with the block remaining in its first well-secured position, which is of course much better where the work to be performed is, as in this case, sufficient to answer the purpose of erecting a Machine exclusively for this purpose.

(373.) The next process is the mortising, and the Machine used in this process is one which belongs exclusively to block making, and requires therefore a more minute description. A plan of this Machine is shown fig. 1, pl. xxx. where *x x* represent two blocks secured in their places by the screws *r r r*, only two of which are shown as acting in the figure; *C D* is a carriage of iron sliding on a proper bearing or bed in the main frame, the advancing movement being communicated to it by means of a screw *L*, fitted through a nut in the centre of the ratchet wheel *M*, which turns round a socket formed to a cross bar *N* of the framing: thus, when the wheel is turned round, it operates upon the screw to advance it with the carriage and block at the same time; the ratchet wheel is turned round at intervals by means of a tooth formed in a rod, nearly the same as the timber is made to advance in a reciprocating saw-mill, the block moving forwards by this means the thickness of the chip it is intended the chisels are to cut at each stroke. The chisels are fixed in a vertical frame and rendered very secure in their places, the vertical frame itself being made to ascend and descend with immense velocity; and there being as many chisels as there are mortises to be formed in all the blocks in the frame, the whole process is performed in a very short time, the chisels moving with such velocity that it is absolutely impossible for the eye to follow them; and to a stranger looking on, the formation of the mortises appears like a work of magic. The ratchet wheel *M* has a cog wheel *P* fixed to it, which has its teeth engaged in a smaller wheel below, (not seen in the figure,) fixed on a long spindle extending to the front of the Machine, which has a handle fixed to it, and by means of which the workman can at any time bring the carriage to the proper point for the commencement of the mortise, and by this means the action of the screw is at any time cast off.

The chisels are provided with small teeth which are fitted into dove-tailed notches formed in the blade of the chisel: these are called scribes. They have a sharp edge projecting a small distance beyond the inside edge of the chisel, and therefore in descending through the mortise, the scribes cut the sides of the mortise clear, and cut at the same time two clefts, which separates the chip, which is to be cut out by the next stroke, at its edges from the inside of the mortise, so that the chip comes out clear without splitting at the edges; thus

Mortising
Machine.
Pl. xxx.
Fig. 1.

Manufactures.

making the inside of the mortise as clean and smooth as possible. Each chisel has also a piece of steel fixed on before the edge, by a screw which projects from the middle of it, and is screwed into its blade, the upper end of the piece being received in a notch or groove formed in the chisel. This piece is for clearing the chips out of the mortise as fast as they are cut; for though in general these fall down through the block, yet it may happen they will stick in, in which case without this precaution they would clog up the mortise with chips so as to impede the proper action of the chisel.

It should have been observed that the screws which secure the blocks in the boring Machines, make a certain central impression and a ring on their ends, and that this centre is the guide for fixing the blocks fast in the mortising Machine, the points on the screws *r, r, r* being carefully introduced into the centre previously made, and the rings of these are also of precisely the same size as those on the screws of the former Machine, and by this means the utmost accuracy of position is attained. We do not attempt to give a graphical illustration of the Machinery by which the motion of the chisels is obtained. The reader will easily conceive a strong vertical iron frame standing over the place where the blocks are represented in the figure with an interior frame carrying the chisels moving up and down in well-secured slides with great velocity, the motion being communicated to the moving frame by Machinery connected with the shaft of the steam engine, and that as the motion proceeds, the sliding frame carrying the blocks is gradually carried forward by the means already described, each advance of the blocks answering to each descending stroke of the chisels, and amounting each time to the thickness of the intended chip.

Corner cutting Machine.

This process being completed, it has been stated that the next consists in cutting off the corners of the blocks so as to approximate them towards the elliptical-shaped figure they are ultimately to have. This process being simply the work of another circular saw, requires no separate description. It will be sufficient to observe that in this, as in every other operation, the fixing and placing the block is so arranged that the most exact performance is insured.

Shaping Machine. Fig. 2.

(374.) The succeeding operation is that of shaping; and here again a Machine is employed exclusively applicable to this purpose, and it is one in which the ingenuity of the inventor displays itself in the strongest light. This consists of a double wheel in which ten blocks are fixed at once. The wheels are then put in rotation, and a gouge is so placed as to intercept them and form their external surfaces to segments of the circle in which they revolve. The plan of this Machine is represented in fig. 2, where *A B* are the two wheels fitted on a common axis, and which together form what is called a chuck. Two of the blocks are represented at *E E*; the figure shows the manner in which they are fixed in their position by the screw *a*, which has a steel ring fitted upon the point of it, exactly the same in all respects as the ring on the point of the screw *r* in the last figure. This ring of the screw *a* being inserted into the impression made in the end of the block while in the boring and mortising Machine secures one end. The other is retained by a ring *b*, of the same dimensions, containing two others within it, which enters the impression made in the other end of the block by corresponding sized rings in the mortising Machine. The

Machinery

double ring *b* is formed in the end of a short spindle, fitted in a socket through the rim of the great wheel *A*, exactly opposite the screw *a*, and has on the outside of the wheel a small toothed wheel *d*. The screw *a* being tightened up by a winch, the block becomes fastened in between the point of it and the spindle *b*, as if it were in a lathe. The compound wheels *A A, B B*, or as it is called the chuck, being thus fitted with blocks, has a rapid circular motion given to it by means of an endless rope encompassing the pulley *F* on the main axis. It is evident that a cutting tool being now presented to the blocks as they revolve, will form their exterior surfaces to segments of circles of the diameter of that in which they revolve. This tool, which is a gouge, is held in a sliding rest; this consists of a dove-tailed slide *G* accurately fitted into a groove *H*, which is attached to a long metal bar *I*, curved to a segment of a circle at one end; this is fitted on a centre piece fixed in a cross bar of the frame exactly beneath the centre of the axis of the chuck. The other end of this bar, which may be called the radius, rests upon a part of the framing *L* which is curved to a circular size, and on this the radius rests as it sweeps on its centre from one side to another of the Machine. The slider *G* for the gouge is advanced to its work by a lever having a handle *m* at one end, the other being fitted on a centre pin *n* fixed in a projecting part of the frame *H*; to the middle of the lever a short connecting bar *h* is jointed, and communicates the power of the lever to the slider *G*, and consequently advances the gouge *g*, which is held in the end of it, towards its work; but the quantity of this advance is determined by a roller, the axis of which is fitted in a socket attached to the slider *G*; it bears against a guide or pattern ruler *N*, which is supported on two pillars from the frame of the Machine. This pattern ruler has such a degree of curvature as the block is intended to have in this direction. This being understood, and the chuck supplied with the ten blocks as above described, the slide rest is moved quite to the end of its slider *L*, and in this state the Machine is put in action. The workman now holds the handle *m* in one hand, and the long handle *R*, which is attached by a joint to the frame *H*, in the other hand; with the former he presses towards the Machine to keep the roller above mentioned in contact with the ruler *N*, and with the other he sweeps the gouge slowly and steadily from one side of the frame to the other. In this circuit the gouge removes the angles of all the ten blocks at once, reducing them on the outside to the shape shown in the figure. This being done, the Machine is stopped, and it is necessary to turn all the blocks round one quarter on their respective axes to present another side outwards that it may in its turn also be brought to its proper figure. This is accomplished in a very ingenious manner, indeed, more ingenuity appears to be employed than the object attained justifies the adoption of. Each of the small spindles *b* has a small wheel *d* fixed upon it, and to each of these an endless screw is adapted. The axis of these screws *f* tends to the centre of the chuck, and each has a small bevelled cog wheel upon it. All these are turned by one large bevelled wheel *O*, which is fitted upon the main axis, but slips round freely upon it when this is in action. This wheel has a pin projecting from a part of its circumference which is detained by means of a stop jointed to the frame at the lower end and forked at top to catch this pin, when it is moved on its joint so as to approach the wheel, but

Manufactures.

when thrown back by a spring in its joint, it is out of action. When the blocks are to be turned round one quarter, this stop is pressed towards the wheel, and the pin, by turning the chuck round, catches on its fork, and prevents the wheel from turning. The workman now turns the chuck round four times, and in these four revolutions of the chuck, the centre wheel remaining stationary, the blocks are by means of their respective endless screws turned round one-fourth of a circle, and the corresponding face of each block is turned outwards to be subjected to the action of the gouge in the manner already described; but the sides now exposed to its action being those in which the mortises are formed, are of a more rapid curvature by employing a different pattern ruler. These sides being faced, the blocks are again turned another quarter round, and then again, when the figure is completed on all sides.

Scoring Machine.

(375.) The next process, and which is also the last, is that of scoring the blocks; this is performed by the scoring Machine, which excavates a groove on the block for the reception of the strap or rope by which it is suspended when in use. This is deep enough at the ends of the block to receive one half the thickness of the rope or strap, but is reduced to nothing where it crosses the pin of the block. This operation is effected by a circular brass wheel, which, in two opposite sides of its circumference, has openings in which are fixed two cutters with round edges projecting a little beyond the rim in the manner of a plane iron, and act as such. These brass wheels (there being two belonging to each Machine) are fixed over the centre of each block that is to be scored, the blocks being first secured in their places by means similar to those explained in speaking of the Machines already described. The frame which carries the blocks turns on an axle, so that they may be inclined to meet the cutter and thus admit of the score being made deep towards the extremities, while it is scarcely seen in the centre. The cutters also are on spindles which turn in a frame movable on a joint at the back of the frame of the Machine; and by means of these two adjustable parts, and a pattern to limit the curvature and depth of the score, this last process is effected and the block is completed, except a slight dressing by hand to remove any trifling roughness which may appear in the mortises when the tools are not in the most perfect order.

Trepanning or crown saw.

(376.) It remains to say a few words on the formation of the sheave. The trees of lignum vitæ being cut in flakes of proper thickness by the converting saw, these are now subjected to the action of the trepanning or crown saw: this may be described as a cylinder of steel having teeth cut upon its end; it is fitted on what may be considered as the mandrel of a lathe, but so as to slide freely upon it with the pulley by which it receives its motion. Within this cylinder is another axis and pulley revolving the axis carrying the borer to form the centre hole of the sheave. The sheave itself is held fast in its position by a screw, in what may be called the back centre of the lathe, and the saw and borer are made to advance upon it by means of a lever or handle urged forward by the workman. Thus the true circular figure is given to the sheave, and at the same time the hole for receiving the coak is also formed and rendered truly central with the circumference; at the same time impressions are made on its surfaces by the rings fixed to the ends of the screws, and the support between which it is held, which impressions serve as guides in fixing it again central in

any future process it has to undergo, such as broaching the coak, &c. Machinery.

The sheave being thus far formed, the next operation is to complete it for the reception of the coak. To comprehend this, it will be proper to describe the form of the coak itself. This consists of a part called the barrel, which just fits the circular hole in the centre above described, at one end of which is a flanch about double the diameter of the barrel, and having at equal distances on its circumference three semicircular ears projecting beyond its circumference. Another plate of a similar form is cast separately, with a central hole sufficiently large to fall over the circular part of the barrel, rather smaller than the main part of the same. The sheave being cut on its two surfaces to the figure of these flanches, by the means described below, the coak is first introduced on one side, and its flanch applied to the figure cut on the surface of the sheave to a proper depth to receive it: the detached flanch is next applied on the other surface to the barrel, and then rivetted as hereafter described. Form of the coak.

(377.) It appears, therefore, that what remains to be done to complete the sheave for receiving the coak, is to countersink its surface to the figure of the flanch on each face, and this is effected by what is called the coaking engine. The operation is performed by fixing the sheave horizontally on a frame which admits of its being placed in any degree of eccentricity with respect to a vertical spindle carrying the cutter, but still in such a way that the three ears must be at precisely equal distances from each other, and from the general centre. The sheave being properly adjusted, a very rapid rotation is given to the spindle and cutter, and a circle is thus cut in the place of one of the ears; the sheave is then turned a third of its circumference round, the exact measure of which is marked and limited by the construction of the engine, when a second circle is cut, and then a third, all to exactly the same depth, which is also determined by a pin properly fixed for the purpose; and lastly, the sheave being fixed centrally, the larger circle from which the ears proceed is cut in a similar manner, this latter circle passing very nearly through the centres of the former. And this process being gone through on the other face, the sheave is completed for receiving the coak. Coaking engine.

The coaks are formed of gun metal, cast in sand from accurate patterns, made for the purpose in the usual way; the only peculiarity which requires to be mentioned is, that the core which is inserted in the sand for forming the hole through its centre is not a smooth cylinder, but has two projecting threads which wind round it spirally in the manner of a coarse screw, so that when cast, the interior surface of the central hole through the coak has spiral cavities or chambers winding round within it, in the manner of the spiral cores of a rifle barrel; but these do not reach to the ends of the hole, which is smooth and circular to form proper bearings. These recesses are intended to contain a supply of grease to the centre pin when the block is in use.

(378.) The next process the sheave undergoes is to have the coaks rivetted in, which is performed by a small rivetting hammer, worked also by the Machine with great rapidity. This does not require any very minute description; it acts after the manner of the usual tilt hammer, but in consequence of the rapidity of the motion, the hammer would not fall with sufficient rapidity to be clear for the succeeding cog of the wheel, if left to the Rivetting hammer.

Manufac-
tures.

mere action of gravity; it acts, therefore, against a spring which facilitates its descent and gives an additional intensity to the blow. In using this Machine, the workman takes a sheave, and, lifting up the hammer, applies it beneath the face of it; then, by shifting the band or strap, which is all the time in motion, from the dead to the live pulley, the axis is put in rotation, and the hammer beats upon the rivets, so as effectually to fasten them in their places. It should be observed that the rivetting is, of course, on the surface having the detached flanch, and by the process the barrel of the coak is slightly shortened, whereby the flanches are drawn into the recesses with such force as never to be again in danger of getting loose. But to make every thing more secure, pins are sometimes inserted through small holes drilled in the centre of the semicircular ears and through the sheaves, which, being also rivetted at each end, gives, of course, additional security; but it does not appear that this process is necessary, nor is it frequently had recourse to.

Broaching
engine.

(379.) The next operation is that of broaching the coak, it being, as far as we have hitherto described it, only in that state in which it is received from the founder. This is done by what is called the broaching engine; the sheave is fixed on a flat chuck, at the upper end of a vertical spindle, which revolves while the borer is forced down perpendicularly through the centre hole of the coak, thereby forming a truly cylindrical and truly central hole, the centricity being secured by the manner in which the sheave is fixed to the spindle. To effect this the spindle is hollow for a considerable depth down it, and the borer is a cylindrical rod which exactly fits into this hole in the end of the spindle, and also fits pretty truly into the centre hole of the coak in the state in which it comes from the rivetting hammer. This cylindrical rod has a small tooth of steel fixed into it, projecting a small distance from the circumference, that is, to the distance to which the centre hole is to be enlarged.

The sheave is, of course, fixed on while the Machine is at rest; while in this state the broach is drawn up by the same screw movement which forces it down when at work, so as to get it clear out of the end of the spindle; the sheaf is then laid upon the flat chuck at the upper end of the spindle, which is larger than the sheave itself. The cylindrical borer is next put down through the centre of the sheave, and entered into the hole in the end of the spindle. By this means the sheave is placed on the chuck, exactly in the centre of it, and both being flat, it only requires to be screwed or clamped fast against the chuck, so as to be turned round at the same time with it. This is done by a clamp, consisting of an iron ring of a smaller diameter than the sheave, having two short bars projecting from the opposite sides of it. These bars extend across the face of the chuck, to which one of them is connected by a joint or hinge, and the other by a screw; or in other words, the clamp may be considered as one bar, having a large hole through the middle of it, one end being hinged to the chuck, and the other drawn towards it by a screw similar to a vice screw, but is so constructed as to be quickly unhooked, and then the clamp bar may be lifted up upon its joint, in the manner of a book lid, to place the sheave under it. The ring or hole through the centre of the clamp, when screwed down upon the chuck, is concentric with the spindle, and thus leaves the centre of the sheave free and clear for the operation of

the borer. The sheave is thus, by means of this clamp, Machinery fastened down upon the face of the chuck in a moment, and the workman sets the Machine in motion. He now, by turning a handle, gives motion to a wheel over head, in the centre of which is a nut, through which the screw in a line with the borer is fitted to work; and this screw, as well as the borer, being prevented from turning round by appropriate fitting at the end of it, is caused to descend, and force the borer down till its cutting tooth meets the bell-metal coak, and cuts its way through, enlarging the hole to its intended dimensions, and making it truly cylindrical to fit the pin on which it will turn when in the block. It has been observed that the interior surface of the hole has two spiral grooves or cavities withinside of it, which are formed in the casting as before described. These are too deep to be taken out in the broaching, and form receptacles for grease, which is thus always kept supplied to the centre pin, both to diminish friction and avoid wear of the parts. This is a great improvement in the blocks, as without such receptacles the pin well fitted into its centre hole, as it is and should be, would afford no room for grease, and then the block would require constant attention to keep it supplied, or would always be in want of it.

(380.) It still remains for us to describe the last operation Facing the sheave has to undergo, viz. the facing and turning the groove for the rope to run in on its edge. This is, in fact, only a lathe, but it is fitted in a most ingenious way to answer its intended purpose. The sheave is fixed to the mandrel by its centre, and a slide rest carries the tool which turns the face; the motion of this cutter, which proceeds from the centre to the circumference, is not perpendicular to the axis of motion, but a little inclined so as to form the face somewhat convex, in order that when placed in the block, it may only touch at the centre, thereby avoiding any unnecessary friction. The motion of the slide rest is governed by the Machine; the facing process requires, therefore, no attention from the workman, except that as the motion for turning gun metal requires to be much less than that for turning wood, as soon as the cutter has passed from the centre to the extremity of the face of the gun metal flanch, the workman, by shifting the band to another pulley, doubles the velocity of rotation while the tool is cutting the wood; and while these processes are going on upon the face of the pulley, the workman in the usual way, with a gouge and common rest, forms the groove for the rope on the edge of the sheave. The face on one side being formed, the sheave is reversed, the second face turned, and the entire operation thus completed.

(381.) All now remaining to be done is to form the pin Pin turning on which the sheave turns. The pins are first forged in a lathe. way not differing from the usual practice, between two swages by two workmen, and rendered thus as truly cylindrical as possible, consistent with the operation of the forge hammer, but at each end they are left for a short distance square to be inserted into the cheeks of the block, that the pin may not turn round by the friction of the sheave when it is put together. The lathe for turning the pins is fitted for this one particular object, and has every motion and all its arrangements most ingeniously contrived; but in its general principle it does not differ essentially from another lathe intended for turning iron, and, therefore, we do not think it necessary to enter into a minute description of it.

The pin thus turned to a truly cylindrical figure has

Manufactures.

Pin polishing Machine.

still another process to undergo, which is that of being polished, whereby it acquires a most perfect surface, and becomes compressed and hardened, so as to reduce the friction to the least possible quantity.

(382.) The Machine used for this purpose consists of three steel dies fixed in a box, and regulated by strong screws to form a triangular opening of any required dimensions. The pin being drawn through these dies, and turned round at the same time, receives a very violent pressure and friction which burnish and polish the whole surface in the most perfect manner imaginable. The dies are, of course, immersed in oil to avoid the heating of the pin or dies by the friction. The pin is fixed, by means of a strong hand vice, to the lower end of a long screw, with which it forms a right line; this screw and pin are fixed in a vertical position exactly over the dies, and the screw is enclosed in a nut or female screw, which is made in two halves, and shuts up after the manner of a pair of tongs round the screw, so that it can be opened and the screw raised or lowered at pleasure, it being properly suspended and balanced by tackle, which furnishes the means of lifting it with ease. Exactly beneath the screw are fixed the dies, these being fitted into an iron frame or box containing the three, each fitted into a proper groove, and adjustable by a screw behind it, to form a triangle of such dimensions that the pin shall exactly fit it. The interior surfaces of these dies are highly polished, and rendered as hard as possible, and the frame in which they are fixed is, as above stated, immersed in oil.

Conceive now the screw at the top of its movement, and the pin fastened to it by the vice above described. One of the screws at the back of one of the dies is now screwed back, enlarging the opening, and admitting thereby the pin. The nut on the screw is now opened, and the pin let down till its square end comes to the dies. The back screw is now brought up to bite the pin, and then closed round the screw. The Machine being now put in motion, and the screw turned round, the pin is also turned round as it is drawn up through the dies, whereby the surface is burnished in the most perfect manner; so that when it comes out it has as high a polish as it is possible for iron to bear, and the surface receives a kind of case-hardening which is very advantageous, as it enables it to bear the friction to which these pins are exposed without any sensible wear or abrasion.

We have thus endeavoured to describe the nature and operation of this series of highly ingenious Machines, the performance of which, through the obliging introduction of the inventor, we have witnessed with satisfaction and admiration; but we are still much indebted, in several of the preceding explanations, to the original descriptions and drawings of Mr. Farey, who in Rees's *Encyclopædia* has illustrated the several operations with numerous figures and plates in a most complete and masterly manner.

Common bellows.

(383.) *Blowing Machines.*—The most simple Machine of this kind is the common bellows; but these, considered simply in relation to their application to domestic purposes, would hardly claim a place in the list of Machines falling under our description; but their use is much more extensive, as in the cases of forging, founding, and general smithing, as well as in organs and other pneumatic instruments. Bellows are constructed of various forms and sizes, according to the nature of the duty they are intended to perform, and furnished with

different kind of apparatus to give them motion, and to force the air from their interior. Beckmann, in his *History of Inventions*, dedicates some pages to the subject of bellows; observing, that after the discovery of fire it is probable the bellows, in some shape or other, soon followed, and he therefore gives them a very early origin; for we can hardly suppose men were long created before either natural effects or accident led to a knowledge of that universal element.

Our common bellows, which consist of two boards joined together by a piece of leather, and which are probably an imitation of the lungs, appear to have been known to the early Greeks; but of what kind of bellows they availed themselves for smelting, forging, &c., is not known. Strabo informs us, on the authority of an old Historian, that Anacharsis, the Scythian Philosopher, invented the bellows, the anchor, and the potter's wheel; but this account is very doubtful, as Pliny, and other authors who have also spoken of the inventions of this Philosopher, mention only the two last, and not the bellows. Leaving, however, these early claims in as much doubt as we find them, it is pretty certain that in the oldest smelting-houses the bellows, such as they were, were worked by men; and such places are still indicated by the refuse of the furnace, where at present, for want of water, such works would not be erected. Bellows of the larger kind, such as those in smitheries and furnaces, formed of leather sides, required very careful management, a constant attention to oiling, &c., inconveniences which first gave rise to wooden bellows.

(384.) These, except the pipe, consisted entirely of wood. The whole Machine was formed of two boxes, placed the one upon the other, the uppermost of which could be moved up and down upon the lower one after the manner of the lid of a snuff-box, having a hinge; but the sides of the uppermost box were so broad as to contain the lower one between them, when raised to its utmost extent: both boxes were bound together at the smaller end by a single hinge bolt, and here also was placed the pipe. It may easily be comprehended that when both boxes fitted each other exactly, and the upper one was raised over the under one, which was in a state of rest, the space included by them would be increased, and that air would rush in through the valve in the bottom of the lower one, and when the box was again forced down this air would be expelled through the pipe. The only difficulty is to prevent the air which forces itself in from escaping any where else than through the pipe; for it is not to be expected that the boxes could fit each other so closely as to prevent entirely the air from making its way between them. This difficulty, however, was obviated by the following simple and ingenious method. On the inner sides of the uppermost box there are placed movable slips of wood, which, by means of metal springs, were pressed to the sides of the other box, and filled up the space between them. As these long slips of wood might not be sufficiently pliable to suffer themselves to be pressed close enough, and as, though planed perfectly straight at first, they would, in time, become warped in various directions, incisions were made in them across through their whole length, at the distance of fifteen or eighteen inches from each other, so as to leave only a small space in their thickness; by which means they acquired sufficient pliability to be every where pressed close enough to the sides to make them sufficiently air tight for the purpose.

Beckmann says that the invention of these wooden

Machinery

Wooden bellows

Manufactures. bellows, which are still in use on the Continent, is certainly due to the Germans. Grignon expressly affirms this; and in Becher's time they were not in use in England, although they were in the former Country: the name of the inventor, however, is not known. It appears that about the middle of the XVIth Century an artist, Hans Lobfinger, who resided at Nuremberg in 1550, furnished the Magistrates of that city with a catalogue of his Machines; from which catalogue it has been concluded that he understood the art of making large and small bellows, both for organs and for melting-houses, and likewise copper bellows, which produced an equable blast of wind; and Beckmann concludes, that as Lobfinger made organs, he himself perhaps was the inventor of the bellows he constructed, but what their actual form was is not known. Agricola, who died in 1555, makes no mention of wooden bellows; so that these appear at all events to have been an invention of about this date, or a little later.

Blowing Machines. (385.) These kind of bellows, however, if they have any existence at present on the Continent, are, we believe, wholly out of use in England; where their place has been supplied by Blowing Machines of the most varied form and construction. In our larger works the blowing Machines are commonly large iron cylinders, worked by pistons, like the steam engine. In some cases three or more cylinders, from four to five feet in diameter, and in length a little more or less than their diameters, with a piston fitting air tight, are placed over or in connection with a large iron wind chest, so that as the piston is forced down by the action of the steam engine or water wheel, the air which was previously in the cylinder is forced into the chest through a valve opening into the same. On the return stroke the air enters into the cylinder below the piston, and is again forced into the chest on the descending stroke, where, as above stated, there are two, three, or more such cylinders connected with the same chest. The strokes of the several pistons are made in succession, and another cylinder is generally attached, which serves as a safety valve or regulator, its piston being free, and loaded with a certain pressure per square inch, or per square foot, according to the nature of the blast which is required. In the Blowing Machine in his Majesty's Dock-yard, Woolwich, there are four cylinders, and the pressure per square inch is a quarter of a pound; when the pressure exceeds this the piston is raised by it, and the air escapes. From the air-chest pipes are connected with all the forges and fires in the smithery, and the air is let on the fire by turning a cock, in a manner very similar to that of turning on water with the common water-cock. The valves here are all of the sliding kind, and the Machine works so quietly that a person might sleep without being disturbed, even in contact with the cylinder.

At Messrs. Crawshaw's iron works. In a very large Blowing engine we have seen at Messrs. Crawshaw's works at Merthyr Tidvil, the valves are placed in the piston opening inward; these are closed by the internal pressure when the piston is descending, but open and admit the air on the ascending stroke; these valves being what are called clack valves, the silence we have remarked in the former Machine must not be expected in this construction. In another Blowing Machine on the same premises, the reservoir for the compressed air is a large iron globe eighteen feet in diameter, which, from its great capacity, preserves the pressure very constant, as it will of course admit several cubic feet to be removed without experiencing any very sensible diminution of elasticity.

Machinery. Another Blowing Machine, or perhaps bellows, the writer has seen at Messrs. Brunton and Co's. iron cable manufactory, which is exceedingly simple and neat. Here a beam, resembling the beam of a steam engine, has a rod suspended from each end, and to the lower end of each of these is fixed a hollow iron vessel of considerable capacity, with its opening downwards; this just reaches to the surface of a quantity of water in a cistern; under the centre of each vessel is an iron tube rising a little above the water, and each vessel is supplied with a valve opening inward. When, by the action of the steam engine, one of the vessels is forced down, the valve shuts by the internal pressure, and the air is forced through the tube or pipe above-mentioned. During this down stroke, the vessel on the other side has been rising, receiving at the same time a supply of air through its valve. This now descends, and delivers its charge of air down a corresponding tube, while the former has made its ascending motion and received a fresh supply, to be discharged again at the next stroke, the same as in the first instance.

Various other kinds of bellows or Blowing Machines might be described, but we shall confine our remarks to only one or two others. Forge bellows are sometimes made to work by means of the reciprocating or oscillating motion of a large cask or vessel, suspended on an axle lengthwise, with a vertical partition from end to end, open at its bottom part; each half being supplied with a valve, a quantity of water filling about one half is now put in, and the vessel is inclined; by this means all the water is found on one side of the partition; the valve on the empty side opens by the pressure of the external air, and, therefore, one half (the lowest) is filled with water, and the upper side with air. If now the barrel or vessel be made to incline on its axis the contrary way, the water passes under the bottom of the partition, and as it occupies the space before filled with air, it drives the latter before it through the tuyau which passes to the furnace or forge; during this process the valve in the other half opens, and the place of the water is supplied with a charge of air, which in its turn is driven out by the next inclination of the vessel. It is obvious the partition we have spoken of needs descend but little below half the depth of the vessel; if it is made to descend too low, it would check the motion or passage of the water from one side to the other.

At Messrs. Sharp and Roberts's engine manufactory at Manchester, there is a powerful Blowing engine of very simple form. It consists of a large external cylinder of nine feet diameter and nine feet long, with an internal cylinder of the same length and of two feet diameter; these are concentric, and between the outside of the inner cylinder and the inside of the outer, are introduced four leaves or spires, which make exactly one revolution in the nine feet length. This is placed in a reservoir of water with its axle level with the surface at one end, and so inclined as to dip to within about two feet of its upper edge at the other end. The axle of the Machine being put in motion by the steam engine, the radial edge of the descending leaf reaches the surface of the water and thereby incloses a certain quantity of atmospheric air, which, as the motion proceeds, is carried along the cylinder till it escapes behind into its reservoir; and as this happens every time each of the four leaves reaches the surface of the water a continual stream of air is obtained, with perhaps as little friction and loss of power

At Messrs. Brunton's iron cable manufactory.

At Messrs. Sharp and Roberts's manufactory, Manchester.

Manufac-
tures.

Boring
Machines.

as possible. Some little but very little of the air does escape in front; the Machine is, however, very powerful and effective.

(386.) *Boring Machines*.—These are of various kinds, according to the nature of the material, and the purpose for which the substance when bored is intended to be applied, some articles requiring much greater accuracy than others. We have in our alphabetical arrangement slightly spoken of the process of boring as performed in the case of ordnance and steam cylinders, both of which, but more particularly the latter, require very great accuracy; so great that, in the finishing process, it is by many makers thought essential to keep the Machine continually at work, from the beginning to the end of the operation, through meal-times, day and night; for if it were discontinued while the cutter was only midway or in any part of its journey, and the cylinder allowed to lose the heat it acquires by the friction of the cutter, &c., a ridge and unevenness would be found in the surface which would be highly injurious to its proper action. In the boring of guns, although they scarcely require so much accuracy as steam cylinders, and are also much smaller in the bore, yet much of the present precision in artillery practice is due to the accuracy with which the boring of our ordnance is conducted. Formerly guns were cast with cores, and all that was attempted was to broach them to a certain size. In this way it was almost impossible to get a straight bore, and balls much smaller than would have been otherwise necessary were obliged to be used to give them any chance of reaching the charge: this allowed of great windage, much of the force of the powder escaped, and any thing but precision was attained in the direction of the projectile. This method has been practised in Turkey and other Eastern Countries to this day, but a proper boring apparatus is at this time being erected in Constantinople, which will of course supersede the old and inaccurate method hitherto practised. This consisted, as already stated, of casting the gun with a core; the gun thus formed was placed vertically between sliders to give it a proper direction, its muzzle was placed downwards, and the boring tool vertically beneath it. The latter was then put in motion by horses walking round it in a horse-mill, and the pressure or weight of the gun urged it forwards as the tool cut away the material. With such means the little value of the Turkish artillery may be easily accounted for. At present, however, the Sultan is erecting one of the most complete foundries in Europe for brass ordnance, and two most perfect boring engines are on their way from England to Constantinople, which will no doubt greatly improve the Turkish artillery.

In boring steam cylinders, a powerful and very accurate engine is required. The cylinder is placed horizontally and fixed in its position while the cutters are made to revolve and advance forward by the action of some powerful first mover, generally either a large water wheel or steam engine, and the operation is commonly repeated three times, in the last of which the greatest care is required, and in which, as has been already stated, the engine is continued in motion from the beginning of the operation to the end.

Ordnance have been bored in two ways; in one, the gun revolves and the borer advances, and in the other the gun was fixed and the cutter made to revolve. The former, however, is always adopted in brass guns, and as the gun revolves, its exterior surface is turned, which

is a great advantage, for in this way the bore is necessarily central and the face of the muzzle perfectly square with the bore of the piece. These processes have been already explained in the article referred to above.

(387.) *Machine for boring wooden pipes*.—Before the very general introduction of iron for forming water pipes, the boring of wooden pipes for this and for similar purposes was a mechanical operation of some importance, and, accordingly, different ways of effecting the object have been proposed and are described by different writers. A Machine of this kind is given by Belidor, where the tree to be bored is mounted on a carriage and well secured in its place. A vertical spindle, put in motion by a water wheel, driven by means of a trundle and face wheel, gives a rotary motion to a horizontal bar, carrying at its extremity a borer or auger; as this is made to revolve, motion is given to another wheel, about the shaft of which a rope is attached, which is also fixed to the carriage bearing the tree, so that, as the borer cuts its way, the carriage is gradually drawn towards its work till the hole is cut through. The carriage being now run back, a larger auger is introduced, and this operation is repeated till the bore attains the requisite diameter.

In other cases, the tree is made to revolve and the cutter remains still, except being advanced against the tree after the manner we have described in boring ordnance, but of course with less attention to accuracy, which is not in this case very essential. In some cases the tree is placed vertically, as also the borer, so that as the work proceeds the chips necessarily fall out as they are cut, which is attended with some convenience. It is obvious, however, according to all these methods, the part of the timber excavated is destroyed, namely, converted into chips; and this consideration has given rise to a very ingenious Machine, whereby the core is cut out whole, and is of course applicable to other useful purposes. This consists of employing a hollow cylinder armed at its extremity with a circular saw of the trepanning form; the cylinder being put in rotation by proper Machinery, the saw cuts its way and the core enters the hollow of the cylinder as the latter advances, and is thus preserved whole. It will not be necessary to describe this process more particularly, as in the following article a similar Machine is explained, which may be made applicable not only to boring wooden pipes but also to the formation of stone pipes and columns, such changes being made in the saw as the different materials may require.

(388.) *Boring Machine for forming stone pipes*.—This is an ingenious Machine invented by Mr. Murdock, who took out a patent for it in 1810, and by it the inventor also forms round pillars of stone. It consists, indeed, of a method of cutting out from a piece of a stone a solid cylindrical core, consequently the forming the cylinder is as much a part of its operation as that of making the hollow within, and when the first cylinder is large enough a second core may be taken out, so that little or no waste of material takes place except about half an inch round the core in which the tool acts. The method of performing this operation is shown in pl. xxx. fig. 3, and is described by the inventor as follows.

First, the block of stone is set upright or nearly so, and in the centre of the intended pipe or cylinder is placed a plug of wood or iron Z, having in its centre a hole to fit the pivot of the perpendicular axis or spindle A A. This spindle is considerably longer than

Machinery.

Machine
for boring
wooden
pipes.

Boring
stone pipes.
Pl. xxx.
Fig. 3.

Manufactures.

Machinery

the pipe or column to be formed, and of a size proportional to the nature of the work. This is either triangular or square, or feathered, so that the tube which has a like formed perforation may slide down upon it at the same time that it is put in rotation by it. Upon the upper end of the spindle is fixed a hollow socket B, which fits tight upon the spindle, and on the centre of this socket is fixed a pulley *cc* or toothed wheel, by means of which it receives its rotary motion; the upper and lower parts being cylindrical to serve as gudgeons on which it turns, in a fixed frame of iron, wood, or other material. Near the lower end of the same spindle is attached a wheel or cross J J, shown also in fig. 4, with arms, having a hole in its centre which fits the spindle, and the circumference of this wheel or cross is made like a hoop, two, three, or four inches deep, its diameter a little exceeding the core to be cut out, and fits to the inside of the tube L L, so that the latter may slide easily over it. This is made fast to the spindle by a screw or key, but may be taken off at pleasure. The tube L L may be of iron, brass, or copper, and is of course a little less in its external diameter than the inside diameter of the pipe, while its interior diameter a little exceeds the exterior diameter of the central core, and to its lower edge is fixed the saw or cutter for forming the cut, which, ultimately, separates the core from the exterior part, thereby forming the intended pipe.

The tube to which this cutter is fixed, is connected with the axis or spindle by means of a second wheel or cross *k k*, which is fixed by its circumference to the inside of the tube, having a hole in its centre which corresponds to the figure of the spindle, and slides freely upon it, so that the tube may be slipped up or down the spindle, but always remaining concentric with it. To one of the arms of this cross is fixed a small cord, (or it may be a chain rod or rack,) which passes upwards through a hollow in the axis of the spindle, and, in case of its being a rope, over a pulley fixed at a convenient height; it then passes from that pulley to a windlass to which it is attached. The use of this is to raise or lower the tube upon the axis, which may be done even while it is in motion. The weights N N are for pressing the cutter downwards, and must be of course proportioned according to the nature of the work to be performed. The pulley or pinion *cc* is fixed upon the socket which receives the upper end of the axis, and is generally made about twice the diameter of the tube.

When the apparatus is to be put in motion by the force of men, a rope E E is wound round the pulley *cc*, the ends of the rope then pass over two other pulleys F F, only one of which is shown; the ends then turn downwards, and having handles attached to them, they are pulled alternately by two men, one on each side the spindle, whereby is obtained a rotary reciprocating motion which is found much more efficient in sawing stone than a continuous motion. S is a cistern furnished with a cock which supplies the inside of the tube with water, which by its pressure forces itself under the saw, carrying away with it the stone and sand which have been used in the process, in the form of mud, over the top of the block of stone under operation.

The method of applying a similar Machine for boring wooden pipes is obvious. In this case, the tree is best placed vertically above the spindle and cylinder, as this position admits of the dust falling out of the saw kerf as the operation proceeds.

(389.) *Calender and mangle.*—We combine these two

articles, because, although receiving different denominations they are the same in principle; the calender being but a larger sort of mangle, or the mangle a smaller sort of calender. The calender is employed in the dressing new goods, and the mangle for domestic purposes after washing, &c. In dressing cloth, two different processes are adopted. In the first such a degree of compression only is employed as is sufficient to remove any creases or folds which the cloth has previously received, and at the same time so to compress the surface as to render both sides smooth, uniform, and level. The second, besides effecting this, adds a gloss to one side of the cloth; the former is generally called dressing, the latter glazing.

The original calender for dressing cloth consists of a large, strong, and smooth bed of wood, or metal, or marble, and a large case also of wood or metal resting on it upon wooden rollers, the case being made very heavy by being filled with stones, lead, or other heavy bodies; this weight sometimes amounting to some tons. The goods to be calendered are carefully wound on these rollers, and are then placed upon the bed with the weight above mentioned resting upon them; one of these rollers is near one end of the calender or case, and the other about the middle; then as the large box or case is drawn alternately from one end to the other of the bed, the rollers become alternately situated at the end and middle. When the operation has been carried on long enough, the calender is easily tilted, or will tilt of itself on the centre roller; the other roller is then removed, a new one introduced till the case is again tilted at the other end, when the second roller is removed and replaced.

The calender is drawn backwards and forwards by two ropes, one fixed to each end of the case, which are wound and unwound alternately upon an axle, and the work may be performed either by men, horses, or steam power, water wheels, &c. when the Machinery is properly arranged for the purpose; but without some means especially contrived to avoid it, it is necessary to invert the motion of the handle to give the alternate motion to the case as above described. This is effected in various ways, but one of the neatest is that employed in Baker's patent mangle.

(390.) This consists in having an axle and pinion so fixed, that the latter acts upon the teeth of a face wheel, which occupy only the segment of a circle instead of the circumference, and the pinion is made to act first on one side of these teeth, and then on the other. Supposing, for instance, the leaves of the pinion are first acting inside the face teeth of the segment, and that while thus acting the mangle moves to the right. At the end of its journey the pinion will have reached the extreme tooth on the segment, and by continuing the motion of the axle the pinion would move on, but it is here caught by an arc formed on the segment wheel round the end of the teeth, and turning on this arc it is guided to the outside of the teeth, and the motion continuing, it now acts on the outside and drives the wheel back, till it arrives at the other extremity of the teeth, when it is again caught by a similar arc and turned inside; so that by a continuous motion of the handle a reciprocating motion is given to the mangle, which is furnished with a fly wheel to assist the pinion over the ends of the teeth as above described. Moreover, as it is obvious the pinion must in such case have some play, the axle is so arranged as to allow this, the pinion being kept to its

Baker's mangle.

Manufac-
tures.

Calender.
Pl. xxx.
Fig. 4, 5.

work by contact with the top or bottom of the space cut to allow this play, *i. e.* by its upper part during the action of the pinion, on one side of the teeth, and by the lower during its action on the other side.

(391.) Other means are employed in the larger calenders, but it will be unnecessary to describe them, as the best and most general sort of calender employed in our larger Manufactories are of a cylindrical form after the manner of the rolling mill. A calender of this kind commonly consists of five cylinders; as represented in pl. xxx. fig. 5. These are fixed in a strong wooden frame A, consisting of strong upright posts connected at the top by a strong cross piece, fixed to the upright posts by screw bolts, besides which there is usually another cross rail below secured in the same manner. Of the five cylinders shown in the figure, those marked *b, d* are of cast iron turned very smooth and hollow in the centre for the purposes of admitting cylindrical pieces of hot iron when the calender is to be heated. The main cylinder *c* was formerly of wood, but being very liable to split by the heat employed, this is now generally made of compressed paper, which is found to answer much better, and to be most economical, although the first cost is considerably greater. The advantages of this paper cylinder consists in the perfect smoothness that can be given to the surface, and in its having no tendency to either warp or split, to both which evils the wooden roller is very liable. The upper and lower cylinders, technically called *bowls*, marked *a, e*, are generally of iron or wood, of the same diameter as *b, d*.

For the common smoothing operation of the calender, it is only necessary that these five cylinders should be made to revolve on their respective axles, the motion of each having an inverse direction to that of those with which it is in motion, and the motion must be in the inverse ratio of their diameters, so that there may be no rubbing between the surfaces. The motion is transmitted from the moving power by a belt passing over the pulleys at D, the one being fixed upon the axle of the main cylinder *c*, and the other a loose pulley. Thus when the belt is upon the fast pulley, the calender will be in motion, and when it is shifted to the loose pulley, the calender will stop without interrupting the motion of any other Machine acted upon by the same power.

The large cylinder *c* being set in motion, the iron cylinders *b, d* receive their motion by means of the wheels C C, worked by the wheel B, on the axle of the large cylinder. The cylinders *a, e* will work sufficiently accurate by their friction with *b, d*, or their motion may be rendered certain by two other wheels pitching into the teeth of the wheels C C. Standing in front of the calender, the operation may be described as follows. The cloth coming from behind above the uppermost cylinder *a*, it passes between *a* and *b*, passing behind *b* it comes to the front between *b* and *c*, between *c* and *d* it is again carried behind, and lastly brought in front between *d* and *e*, where it is received and smoothly folded on a clean board or in a box, by a person placed there to receive it.

Here, in fact, terminates the operation of the calender; but the cloth has still to be pressed and packed, and it may not be amiss to describe the remaining part of the process. In folding the cloth at this time, care must be taken that it may be done very loosely, so that no mark may appear till it is again folded into the precise length and form into which the piece is to be made up. The

folding is done either by two persons or by one, with the aid of two sharp polished spikes placed at a proper distance to ascertain the length of the fold and to make them all equal. When thus folded into lengths, it is again folded across upon a smooth clean table, according to the shape intended, which varies in different kinds of goods.

In general, it is desirable to have goods well smoothed and folded so as to occupy as little bulk as possible in packing. When the pieces have received the proper folds, it is necessary therefore to submit them to a heavy pressure in order to compress them as closely as possible. This is commonly performed by placing a certain number of pieces, divided by thin smooth deal boards, in a common screw press of great power. Besides the wooden boards, a piece of glazed pasteboard is placed above and below every piece of cloth in order that the outer folds may be as smooth and glossy as possible.

The common screw press, however, since the ingenious invention of the hydrostatic press, has been generally superseded by the latter in most large Manufactories; but as this press and its application to different purposes will be described under its proper head, we shall not enter into an explanation of its operation in this particular case.

The calender above described is applicable to the stronger and heavier sort of goods. Lawns, muslins, and goods of a light fabric undergo a similar sort of process in a smaller Machine, which has only three rollers, and as the goods require to be only well smoothed, but little pressure is required, the Machine works lightly, and the work is commonly performed by a man at a handle or winch fixed to the axle of the middle roller. In these calenders the middle roller is a very smoothly turned iron cylinder, the other two are of wood, and the Machine is always worked cool. Book and mull muslins, which are finished with starch at the bleaching, to give them a clear and wiry appearance, receive no other finishing at the calender than folding and pressing. And on the other hand, some goods, before passing through the calender, have to be singed; an operation which requires great care, as the whole surface of the piece is passed over a semi-cylinder of red-hot iron, in order to destroy the rough woolly nature of the surface. In this process a steady uniform motion is requisite, for if the motion be too rapid, the operation will be very unequally and imperfectly performed, and if too slow, the piece is immediately destroyed; such accidents, however, but seldom occur after the operator has acquired confidence by a little practice.

(392.) In fabrics of thick cloth, including both those kinds which are used for many household purposes, and those for the dress of females, the operation of glazing is used both to add to the original beauty of the cloth, and to render it more impervious to dust or smoke. The glazing operation is performed entirely by the friction of any smooth substance upon the cloth; and to render the gloss brighter, a small quantity of bleached wax is previously rubbed over the surface. The operation of glazing by the common plan is very laborious, and the apparatus is of the most simple kind. A representation of it is given in fig. 6, 7. A is a table, with a thick stout cover of level and well-smoothed wood, forming an inclined plane, that side where the operator stands at work being the lowest, and is generally placed near a wall, as represented in the figure, both for convenience in suspending the glazing apparatus, and for

Machinery

Glazing.
Fig. 6, 7

Manufac-
tures.

the sake of light. A long piece of wood B is suspended in a groove formed between two longitudinal beams D D, placed parallel to the wall, and fixed to it. The groove resembles exactly the aperture between the sides of a common turning lathe. The lever B, of which the groove may be supposed to be the centre or fulcrum, is faced at the bottom with a semicylindrical piece of finely polished flint C, which gives the glaze to the cloth stretched upon the table below. Above the flint are two cross handles B B, of which the operator lays hold, and moves them backward and forward with his hands, keeping the flint pressing slightly upon the cloth. When he has glazed a portion equal to the breadth of the flint C, he moves his lever between the shears D D, and glazes a fresh part; thus he proceeds from one side or selvage of the cloth to the other, and when all which is upon the table is sufficiently glazed, he draws it over, and exposes a new portion to the same operation. To preserve the cloth at a proper tension, it may be wound smoothly upon a roller or beam, revolving upon its own axis, and behind the table another roller to receive the cloth may be placed before both, being secured by a catch, acting in a ratchet wheel.

Glazing
calender.
Fig. 8.

To save a great part of the labour employed in glazing cloth, the common five bowl calender has been altered to fit this purpose, and upon some years' trial has succeeded to the satisfaction of those who use it. It is still confined to the extensive calender works of the late Mr. Miller of Glasgow, and was the invention of his superintendent. A profile view of this Machine will be found in fig. 8. It consists of five bowls or cylinders, like the common calender, but instead of the bowls revolving with a velocity in the inverse ratio of their respective diameters, so as always to present an equal surface, and to act merely by their pressure against each other, the bowls or cylinders *b* and *d* move with greater velocity than the bowls *a*, *c*, and *e*, and thus create or generate friction at three several parts of the operation. This difference is produced merely by the addition of a few wheels; and the difference between the common and glazing calender will be seen at a single glance, by comparing the wheel-work of fig. 5 and 8. In fig. 5 the motions of all the cylinders is in the inverse ratio of their diameters, so that each presents an equal surface. In fig. 8, the motion, instead of being directly communicated from *c* to *b*, as in fig. 5, is given by the intervention of two additional wheels. The increase of motion depending entirely on the relative number of the teeth in the wheels B and C on the axes of the cylinders *c* and *b* to each other, (for the intermediate wheels E and F merely communicate the motion without affecting the velocity,) *c* is made to revolve considerably quicker than in the common calender, and thus the necessary friction is created. To change the glazing to the common calender, it is only necessary to remove the wheels E and F entirely, and to substitute a larger wheel for the wheel B, which may be calculated to work directly into the wheel C. The profile view given in this figure affords an opportunity also of showing the way in which the cloth is conducted from the table H over the roller I, through the calender, and received again at G. This is common to both calenders. A patent for Scotland was taken for the glazing calender; and upon a trial of some years, it has met with the entire approbation of those who have been in the habit of having their goods glazed

by it. As one Machine, by being worked day and night, Machinery is capable of glazing nearly 1000 pieces of cloth of twenty-eight yards each in a week, it is peculiarly adapted for the occasional hurry to which shippers are sometimes unavoidably subjected. Brewster's *Encyclopædia*.

(393.) *Capstans, crabs, cranes, and other Machines* Original form of the capstan. *for raising heavy loads.*—These are of various forms, indeed they are too numerous for us to attempt any thing like an individual description of them in this Work; at the same time some general account will be necessary. The invention of the capstan is of very questionable date; it appears that it was first used in British vessels during the reign of Elizabeth, but it was in use before that time in the Spanish and Portuguese service. The capstan in its original form is exceedingly simple, consisting only of an upright barrel or drum turning on a vertical axle; on the upper part of the drum is fixed the capstan head, with holes or sockets sunk in the same for receiving the capstan bars, which project about ten or twelve feet, and to these (generally eight in number) the strength of men is employed to urge the capstan round, the weight being raised by means of a rope winding round the barrel. In this simple form, however, great inconvenience is experienced by the necessity of always keeping the power applied to prevent the weight running back; and obvious as the means are which are now employed for preventing this recoil, it was many years after the capstan was known that these were introduced. The French Royal Academy first saw the necessity of some improvements in this useful Machine, particularly in its application to naval affairs, and proposed the subject as a prize Essay. This led not only to great change in the methods of *palling* the capstan, which had before been introduced, but also to great changes in its form and manner of acting. The falling palls now generally used in the common, and indeed in all kinds of capstans, was the invention of Lalande, the celebrated French astronomer. These palls are commonly attached to the lower part of the barrel turning on a pivot, so as to rise as the capstan is urged forward over any obstacle, after which they fall by their own weight into steps of iron made to receive them, and which, in case of any recoil, checks, in the most effective manner, any retrogradation of the weight or purchase; but when it is necessary to reverse the motion, the palls are turned over on their pivots, when they act as effectively in the opposite direction.

In the first rude form of the capstan the barrel was plain and cylindrical, and great difficulty was experienced in surging the rope, or as it is termed on ship-board, the messenger. The barrels are now furnished with additional pieces securely fixed to the barrel, called *whelps*, and the capstan head is securely bolted down, as well to them as to the barrel, and these being trimmed slightly conical, greatly facilitate the surging of the rope, which is thus received and delivered without rising or falling from its proper place.

This simple form of the capstan and its power are too well known to require any further illustration in this place. The power, of course, depends upon the length of the bar, or rather on the distance of the centre of pressure on the bar, and on the radius of the barrel, including the whelps and half the thickness of the rope. When only one man is working at a bar, the power with which he pushes, multiplied by the distance from the axis, will express the effect of his power; and this,

Manufac-
tures.

when there are several bars multiplied by the number of them, will be the whole power, and this is equal to the weight multiplied into the radius of the barrel; but when there are several men to a bar, the centre of all their positions at each bar must be accounted the centre of pressure; in other respects the calculation is the same.

Phillips's
capstan.

It has been stated, that a variety of forms has, within these few years, been given to the capstan. One by Captain Phillips, Royal Navy, has been somewhat largely introduced into the British Navy; this is called a power capstan, as it is made to gain by wheelwork a power of four to one. This Machine is described under the article Capstan, in our general alphabetical arrangement.

Smith's
power cap-
stan.

Another power capstan has recently been invented by Mr. Smith, and is introduced into some merchant vessels, which has the advantage of avoiding the use of the capstan bars, being worked by a crank or winch, which is an object of great importance in trading vessels, particularly in steam vessels engaged in conveying passengers; for the winches may be placed either fore and aft, or transversely from the capstan to the ship's side, without interrupting or abstracting from the convenience of the persons on board when in use, and when not wanted for actual service, they are removable the same as the capstan bars. In this Machine the head of the capstan is furnished with a strong bevelled wheel, in the teeth of which works an endless screw on one side the capstan or on both; the endless screw is worked, as above stated, by a winch which has a bearing at the other end in the ship's side, so that several men may work at once, and the power gained by the endless screw being very considerable, fewer men are requisite to work this capstan than to work the common one, and certainly by dispensing with the capstan bars it allows of more cabin room or more stowage; but unfortunately its friction is very great, and, of course, in this, as in all other mechanical constructions, what is gained in power is lost in time, so that the operation of this capstan may perhaps be found too slow.

Eckhardt's
capstan.
Pl. xxxi.
Fig. 3.

(394.) A different sort of power capstan has been proposed, in which the power gained is almost unlimited, but it is not fitted well for naval purposes; this is the invention of Mr. Eckhardt, and may answer equally well or better as a crane. This is represented in plate xxxi. fig. 3, where A D is a compound barrel consisting of two cylinders C, D of different radii. The rope D E C is fixed at the extremity of the cylinder D, and after passing over the pulley E, which is attached to the load by means of the hook F, it is coiled round the other cylinder C, and fastened at its upper end. A B is the bar by which the compound barrel C D is urged about its axis, so that the rope may coil round the cylinder D, while it unwinds itself from the cylinder C. Let us now suppose that the diameter of the part D of the barrel is 21 inches, while the diameter of the part C is only 20, and let the pulley E be of any diameter. It is evident that when the barrel A D is urged round by a pressure exerted at the point B, 63 inches of rope will be gathered upon the cylinder D, and 60 inches will be uncoiled from the cylinder C by one revolution of the bar A B, these numbers representing the circumference of each cylinder. The quantity of wound rope, therefore, exceeds the quantity that is unwound by 63 - 60, or 3 inches, the difference of their respective perimeters; and the half of this quantity, or $1\frac{1}{2}$ inches, will be the

space through which the load or the pulley E moves by Machinery. one turn of the bar. But if a simple capstan of the same dimensions had been employed, the length of rope coiled round the barrel by one revolution of the bar would have been 60 inches, and the space described by the pulley or load to be overcome would have been 30 inches. Now, we know in Mechanics, that the power of any engine is universally equal to the velocity of the impelled point, divided by the velocity of the working point, or to the velocity of the power divided by the velocity of the weight, that is, to the velocity of the point B divided by the velocity of the pulley E; consequently, if the lever in both capstans be the same, and the diameter of their barrels equal, the power of the common will be to the power of the improved capstan as $1\frac{1}{2}$ to 30, that is, inversely as the velocity of their weights, and the power of the latter will be $\frac{30}{1\frac{1}{2}} = 20$, or in other words, will be equivalent to 20

fold tackle of pulleys. If it be wished to double the power of the Machine, we have only to cover the cylinder C with laths a quarter of an inch thick, so that the difference between the radii of each cylinder may be half as much as before; for the power of the capstan increases as the difference between the radii of the cylinders is diminished. As we increase the power, therefore, we increase the strength of our Machine, while most other engines are proportionably enfeebled by an augmentation of power. Were we, for example, to increase the power of the common capstan, we must diminish the barrel in the same proportion, supposing the bar or handspike not to admit of being lengthened, and we not only weaken its strength, but destroy much of its power by a greater flexure or bending of the ropes.

The reader will perceive that this capstan may be converted into a crane or windlass for raising weights, merely by giving the compound barrel A B a horizontal position, and substituting a winch instead of the bar. The superiority of such a crane above the common one is obvious from what has been said; but it has this additional advantage, that it allows the weight to stop at any part of its progress without the aid of a ratchet wheel and catch, from the two parts of the rope pulling on contrary sides of the barrel. The rope, indeed, which coils round the larger part of the barrel acts with a larger lever, and, consequently, with greater force than the other; but as this excess of force is not sufficient to overcome the friction of the gudgeons, the weight remains stationary in any part of its path.

A crane of this kind was erected in 1797 at Bordenton, in New Jersey, by Mr. M'Kean, for the purpose of raising logs of wood to the frame of a saw-mill, which was 10 feet distant from the ground. The diameter of the largest cylinder was 2 feet, and its length 3 feet; the other cylinder was 1 foot in diameter, and of the same length with the largest. The difference of their circumference, therefore, was 3 feet, and the log would move through a space of 18 inches with one turn of the handspike, and through the required height with only 8 turns. The length of the bar or handspike was 6 feet, which, at the point where the power was applied, described a circle of about 30 feet, so that the power of the crane was as 1 to 20. The length of the rope was only 55 feet, whereas if the weight had been raised through the same height with a similar power, by means of a tackle of pulleys, 270 feet of rope must have been employed.

Manufactures.

Windlass.

In the latter case, however, the rope sustains only one-twentieth of the weight, and in the former it supports one half of the load. *Ferguson's Lectures* by Brewster.

(395.) *Windlass*.—This may be considered as a horizontal capstan; in the latter Machine the barrel is generally placed vertical; when placed horizontally, whether it be worked by a winch as in the common erections over wells, or by movable bars, as on board vessels, it is called a windlass. The latter Machine on shipboard is commonly placed forward, the capstan always aft. The ship windlass consists of a horizontal barrel turning on an axle in two fixed sides with holes or sockets for receiving bars or handspikes by which it is worked. One man, for example, having introduced his bar about six feet in length in a hole nearly vertical, steps up, and, seizing it as high as he can reach, throws himself backward, and as it advances he presses with greater and greater weight upon it till he brings it horizontal; this brings some other hole or holes vertical, into which another man inserts his bar, and thus the windlass is made to revolve, winding a rope about its barrel precisely as in the common capstan, except that here there is a perpetual shifting of the bars, whereas in the former they remain fixed during the operation; the bars are also shorter and the power considerably less, not only in consequence of the bars being shorter, but because fewer men can be employed. This kind of windlass pulls itself by means of a falling pall upon a wheel with proper shaped teeth for the purpose.

Crane.

(396.) *Crane*.—This is also a Machine, in its common form very well understood; it is used for raising heavy loads in a vertical direction, and is therefore furnished with a long projecting gib or neck, which, from its supposed resemblance to the long neck of the crane, has thereby derived its denomination. The simple crane which we see attached to the sides of warehouses is a simple gib of this kind, which sometimes, when not in use, is shut close back against the wall; this gib carries a pulley, over which a rope is passed to a windlass, and the other to the weight to be raised. When it is brought to its proper height, the crane is swung round to bring the load close to the door into which it is to be received, and being landed on the floor, the crane is again swung out, the rope descends, and another weight is raised, and so on. The cranes on the sides of wharfs are similar in principle, but frequently more powerful. These are made to turn on a long vertical axis, which descends to a considerable depth in a proper recess sunk to receive them, and left so that a person may descend to supply them with oil, &c. Some variety of cranes have been described under that article in our alphabetical arrangement, and various other kinds may be seen in almost every Work on Mechanics, their forms being almost infinite, and the modes of working them also very various. Formerly, walking wheels were very commonly employed for working cranes, and even horses and asses have been thus made to do the duty. They may also be worked by horses as in a horse mill, but more commonly they are worked by men at winch handles, and commonly in the better sort of cranes there is the means of engaging different powers, and an apparatus for swinging the crane round when the load has been raised above the level of the wharf.

Sometimes the waste power of a steam engine is employed in working cranes, and this on two different principles, one by the compression of air in a strong vessel, and another by exhaustion or by rarefying the air in a receiver; the power to give motion in the latter

being the pressure of the atmosphere above that of the Machinery. air in the exhausted receiver, and in the other by the excess of pressure of the condensed air above that of the atmosphere. Both of these are patents, the former by Mr. Wright, and the other by Mr. Hague, engineer and millwright of Ratcliff.

Mr. Wright employs for his purpose what he calls a reciprocating rotary engine, by which compressed air, admitted from a reservoir, is to work the crane. This consists of a flat iron cylinder, in which a piston, made to occupy the place of the radius, turns round an axle, placed in its central line, through the whole space between that line and the circumference. A partition is fixed across in one part of the cylinder from the centre to the periphery, which confines the motion of the piston to a single revolution in each direction at one time, or obliges it to "reciprocate," as it is called, round from one of its sides to the other alternately; a tube passes from the reservoir of compressed air to the extremity of this partition, where it enters a cock with two ways, which forms a communication with this tube, and the different sides of the partition, and also with the latter and an eduction pipe, according as it is turned; in one position letting the compressed air press at one side of the piston, so as to force it forward in that direction, while it leaves open a free passage between the air at its other side and the atmosphere through the eduction pipe; and in the other position, causing the compressed air to act on the side of the piston opposite to that on which it first operated, and leaving the communication with the atmosphere open at the side where the compressed air before entered.

On the axle round which the piston turns, and to which it is fastened, a crank is formed outside the cylinder, which by a connecting bar acts on a similar crank attached to the axle of a pinion, the teeth of which interlock with those of a large wheel that is fixed to the barrel of a crane of the common species; and a fly wheel being placed on the axle of the pinion, by its momentum makes the motion this receives from the crank of the air engine be continuous, instead of being alternately reversed, as is that of the latter crank, and thereby turns round the barrel. Two other revolving air engines are likewise described in the patent, which may be applied to the same purpose as that mentioned; one of which is similar to the rotary steam engine for which Mr. Wright obtained a patent in October, 1825, an account of which is given in the third volume, second series, of the *Repertory of Arts*.

(397.) Mr. Hague proposes as the actuating force for working his cranes, the pressure of the atmosphere operating on a piston in an oscillating cylinder, (see Art. 206.) to whose opposite side a communication is opened with a vacuum or partial vacuum, made in a vessel of proper form and capacity, communicating by means of a long tube with an exhauster worked by an air pump attached to the beam of the steam engine in any part of the establishment.

The crane itself that is to be worked by this method is of the common sort, in which a cord or chain is wound upon a horizontal cylinder, that is made to revolve by a series of toothed wheels, ultimately urged by a pinion; and the force mentioned is made to work this crane by having a crank formed in the prolonged axle of that pinion; to which crank the piston rod of the air cylinder above mentioned, (after being properly supported by a cross head and guides fastened firmly to the latter.) is

Wright's method of working cranes.

Hague's method of working a crane.

Manufac-
tures.

connected by a joint constructed like others of the same description. A fly wheel is also fastened to the end of the same axle, to equalize the action of the crank; and the communications between the different extremities of the cylinder with the atmosphere and the vacuum vessel are alternately reversed by means of a cock with four ways, which communicates with two passages formed in one of the gudgeons of the air cylinder, one of which passages is continued to the top of the cylinder and the other to its lower extremity; this gudgeon has a conical termination, on which a conical cap is pressed by spiral springs, which keep the junctures air tight, while, through openings made in it, the operation of the cock is conveyed to the cylinder, as above stated, according to the direction in which it is turned, by means sufficiently resembling those employed with other cocks of the same sort, not to require here the particular description that is given in the specification.

The gudgeons of the air cylinder are supported on blocks below the barrel of the crane, and from its cock with four ways, a pipe descends downwards to the vertical metal pivot, on which the crane turns; this is made hollow for its reception, and moves in an air-tight box, from which another pipe ascends to the vacuum vessel; which arrangement permits the crane to turn round laterally in the usual manner, without interrupting the passages necessary for the air apparatus.

Much similarity will be observed between the two methods of working last described, both acting by means of the pressure of the air moving from a denser to a rarer medium; but as Mr. Wright employs air compressed beyond the pressure of the atmosphere, while Mr. Hague employs the pressure of the latter only pressing on a partial vacuum, the difference in principle is sufficiently obvious, and there are, we conceive, some differences in the advantages. Mr. Hague's plan does not require such strong vessels as Mr. Wright's, and will be kept air tight with more facility, because the pressure of the atmosphere, which is the operating force used, acts externally in closing and compressing all their parts together; but when the power of his engine is limited, as it can never amount to a force of fifteen pounds on each square inch of his piston, on account of a perfect vacuum being practically impossible. Mr. Wright's method will on the other hand require very strong vessels to retain the compressed air, being more liable to leak as well as to burst, from the pressure acting on them internally; but it will have the advantage of as great a force being employed with it as may be thought proper, or one amounting to several multiples of atmospheric pressure; its reservoir may also be considerably smaller than the vacuum vessel of the other apparatus, (which must be very large, to prevent the pressure on the piston of the air cylinder from diminishing too rapidly,) a circumstance that may save expense, and economize space considerably.

Bramah's
method of
working
cranes.

Another principle or method of working cranes, is by hydrostatic pressure. This method, if not first proposed by Mr. Bramah, was perfected by him, and it has been applied to several powerful cranes, but is not, we believe, very generally adopted. The simplest form of this application for a Machine to raise a heavy weight to any height, is to have the iron gib, of the usual kind, properly fixed at the required height, furnished with the usual pulley or wheel, over which the rope or chain passes, and thence over another pulley over the shaft or upright leg of the crane, which, descending to the barrel, is wound

up by the following contrivance. The hydrostatic cylinder is placed in a vertical position exactly as in the hydrostatic press described in a subsequent page under the word Press, or it may be laid horizontally or in any inclined position; the end of the piston rod is furnished with a long toothed rack which works in the teeth of the pinion on which the barrel is placed, so that when the piston is raised by the pressure of the water from below, the rack turns the pinion and barrel, which, winding up the rope or chain, raises the weight to any required amount within the limits of the Machine, which of course may be varied in any proportion by different length of rack and diameter of pinion.

This hydrostatic principle has the same advantage as Mr. Hague's method last described, viz. that it can be easily transmitted to any distance, and in any direction, by means of pipes conducted along in situations where all other means of conveying the motion would be complicated and expensive in the extreme; thus, in an extensive range of warehouses for a dock or depot, an injection pump may be kept in constant action by horses, a water mill, or steam engine, and may inject water into an air vessel, from which pipes are conducted to cranes in all parts of the works; and by simply opening a cock at any crane, the required load will be instantly raised by the elasticity of the confined air on the enlarged surface of the piston of the crane. The air vessel has, of course, a safety valve, to allow the escape of the water when the pressure becomes so great as to endanger the rupture of the vessels; for it is to be observed, that the power of this principle is irresistible when the pump is worked by a mill, and will burst any vessel without the appearance of strain on the moving parts of the pump.

(398.) *Crab* is a name given to a Machine for raising loads, which is a portable winch and barrel worked by wheel and pinion work, fixed in a cast iron or heavy wooden frame, which may be transferred from place to place wherever its duty may be required. When used, as it frequently is, for raising the weight of the pile engine, it is bolted fast down upon its base, and in other cases to sleepers, or to a heavy wooden frame, to give it a firm standing: it is of very simple construction, which will be immediately understood by reference to fig. 1, 2, pl. xxxi.

Crab.
Pl. xxxi.
Fig. 1, 2

(399.) *Gin* is another Machine employed in raising large stones and other weights, and in artillery practice in lifting large guns on to their carriages, &c. The latter differs a little from the former. It is composed of three long and stout legs, meeting together at their tops, these legs are round poles of about twelve or thirteen feet long, whose diameters at the lower end are about four or five inches, and about three and a half inches above.

Two of these poles can be fixed at a certain distance from each other, by means of two iron bars placed horizontally, one being about four feet long, the other about seven; and a roller is made to run upon pivots turning in cheeks attached to two of the poles; this roller is commonly seven or eight inches in diameter, and six feet long. A portion of twenty inches is left square at each end, and holes made in each to receive the handspikes by which the men turn the roller, but the middle part is made cylindrical, to wind the rope upon it. The transverse iron bars are fixed with one end to one of the poles by means of a bolt, and with the other end to the other pole with a bolt and key, so as to be readily taken out, in order that, when the gin is to be moved from place to place, the poles may lie close

Manufactures. together upon the carriage. There are two iron bands and two iron bolts to fasten each cheek to the poles, for the pivots to revolve in, and iron plates round the poles where the iron bars are fixed. The poles are hooped at each end; and the upper ends have straps through which an iron bolt passes: this bolt keeps the upper ends together, as well as serves to support the block through which the rope passes to the windlass. The block contains two brass pulleys, about which the rope goes, which is fixed to the dolphins of the gun or mortar with another block, containing two brass pulleys likewise. When this Machine is to be used, the whole is laid flat on the ground, the lower end of the single pole extending the contrary way, in order to fasten the upper block after the rope has been turned round both; after this the upper end is raised gradually till the feet of the three poles (each of which has an iron prong) stand nearly at equal distances.

The common gin differs from the above only in not being furnished with a windlass.

Jacks for raising weights. (400.) *Jack* is a name given by English mechanics to a simple kind of Machine employed in lifting great weights to small heights.

Lifting jacks are of three kinds: the hand jack, or jack in the box, which, as we shall see, is worked by a rack and pinion, the screw jack, and the hydrostatic jack.

Pl. xxxi. Fig. 4. *Hand jack*.—This, as we have stated, depends upon the purchase or power gained by the rack and pinion, which will be, of course, proportional to the length of the winch and the radius of the pinion. In pl. xxxi. fig. 4, this Machine is represented in its improved form, having a pall to prevent the descent of the weight in case of the hand being removed from the winch handle, a very important, although a very recent improvement. The whole Machine consists of a block of wood about two feet six inches long, ten inches broad, and six inches wide, is perforated with a square hole or mortise through it lengthwise, for the reception of an iron rack B. This rack is formed with a double claw or horn at its upper end. A small pinion C is made to engage in the teeth of the rack. The axis of the pinion is supported in iron plates bolted to each side of the block, and one end of the axis projects through the side plate, with a square to receive a winch or handle, which being turned round, the pinion raises the rack B in the mortise, and, consequently, the claw or horn up to the load to which it is applied. To prevent the weight of the load running the pinion back, the handle is detained by a hook or link fastened to the outside of the block. When a greater power is required than the simple rack and pinion are capable of exerting, a combination of wheelwork is used, as shown in the same figure, where A A is the block of wood, which in this case is made sufficiently wide to contain the cog wheel F, fixed in the pinion C, which acts in the teeth of the rack B. G is a second pinion of four leaves, working in the wheel F, and the axis of this pinion projects through the side of the block for the winch H to be fixed on it. The block A A is made in two halves, and the recess for the wheel F and pinion G is cut out in one of the halves; the other being laid flat against it, supports the front pivots of the wheel and pinions. The two halves are bound together by strong iron hooks b b driven over the outside. The rack has a claw N at its lower end, projecting outside-wise through an opening or slit cut through, in the front half of the block. This claw can be introduced beneath

a stone which lies nearly flat upon the ground, and Machinery. which, consequently, could not be acted upon by the claw on the top of the rack. To prevent the rack descending when it has a load upon it, the small click a drops into the teeth, but clears it in going up; when it is not required to detain the rack, this click can be turned out of the way sidewise.

Fig. 5 is a screw jack. The block of wood A A is perforated nearly its whole length with a hole sufficiently large to allow the screw B to move up and down without touching. The screw passes through a nut n, fixed firm into the top of the block A; and if the screw is turned round, it must rise up through the nut, and elevate the claw F. This claw is fitted on the top of the screw with a round collar, which allows the screw to turn round without turning the claw; and the claw N, which projects through a groove or opening made in the side of the block, is fitted to the screw with a smaller collar. The bottom of the block has four short points to prevent the Machine slipping when used upon hard ground. To give motion to the screw, the lower half of it is formed into a square, and a worm wheel c is fitted upon the square. The teeth of this wheel are engaged by a worm on the axis of the winch H, and plates of iron a b are bolted on each side of the block, near the middle of its height, to carry the ends of the axis of the winch, and of the worm which is concealed behind the worm wheel c. When the winch is turned round, it causes the wheel c to revolve by the action of the worm in its teeth; and as the wheel is fitted on the square part of the screw, it compels it to turn with it, but at the same time allows the screw to move up and down.

The friction of this kind of screw jack is very considerable; nor is its strength so great as the screw jack shown in fig. 6, 7. In this the screw is not made to turn round, but only to rise and fall; and the worm wheel c being placed very near the top of the block A, has a nut for the screw B to pass through cut in its centre. By this means the nut is turned round instead of the screw, and it requires no collar either at the top or bottom of the screw. The axis of the worm, like the former screw jack, is supported by two iron plates a b, and the end which projects through the plate a is made square for applying the winch H. The worm wheel is shown dotted. The circular part D is a part of the wheel c, and forms a collar for the wheel, and gives also a greater depth of nut for the screw to work in.

Hydrostatic jack.—This is, in fact, a small kind of hydrostatic press, and, of course, very powerful in its action, but it is not so simple in its form as those above described; and it differs so little from the hydrostatic press explained under the article *Press*, that it will be only necessary to say here that the upper end of the piston is supplied with a claw like the common jack, instead of the pressing board or iron table; and as in this Machine the piston rods can have no guides, it is best to have the cylinders open at both ends, so as to admit the plunger to pass quite through, one end of which, i. e. the lower being considerably less than the upper; the pump also in this case is attached to the press, forming thus only one Machine.

(401.) *Copying Machines*.—In a mercantile nation like Great Britain, where such an extraordinary extent of correspondence takes place on affairs of business, not only amongst ourselves, but with all parts of the World, it is very desirable in many cases to take copies of letters and communications, which if effected by actual copying

Copying Machine. Fig. 11.

Manufac-
tures.

by hand would consume a deal of time, employ an inconvenient number of copying clerks, and in cases of confidential and important transactions, divulge matters which it may be desirable to preserve secret. To remedy such inconveniences, a variety of copying Machines have been invented, of which one of the most simple is that by Mr. Brunel. This ingenious Machine, which is a sort of press, is shown in pl. xxxi. fig. 11, where *a* is the bottom of the press, made of the best gun metal, and *b b* a pressing board of wood, having above it a steel plate spring *c c* which rests upon ledges and supports the pressing board by the screw *d*. A strong steel lever *e*, moving on the plane *f*, presses near its centre on the head of the screw *d*, and *g* is another lever moving on the joint *h*, to which the power of the hand is applied. A damping apparatus is necessary for moistening or rendering damp the letter to be copied; this is contained in the box *i*; it consists of a metallic cylinder having several sheets of fine linen rolled round it of the same size as the sheets of paper employed. In using the press the original letter is put into a transferring book, and a blank leaf of paper turned over upon it; a sheet of the damp linen is then laid upon the blank leaf and above that a leaf of oiled paper; the book being shut and introduced between *a a* and *b b*, the hand is applied to the lever *g* which presses down the lever *e* with great power, and communicates the pressure to the book by means of the knob *d* of the pressing board *b b*, and thereby imprinting on the oil paper a legible copy of the letter. It is of course inverted on the side next the latter, but on the other, from the transparency of the material, it is read direct.

Various other description of Machines for this purpose have been invented, and to prevent copying at all a Machine has been contrived to write two or more letters at the same time. It is, however, inconvenient in comparison with the simple process of copying.

Card-
making
Machine.

(402.) *Card-making Machine*.—Before we attempt to speak of the operations performed by this very ingenious piece of mechanism, it may be necessary to say a few words with reference to the card itself. In the cotton, woolen, and some other Manufactures, the material has to undergo a process called carding. This may be said generally to consist in passing the cotton, wool, &c. between cylinders, on which strips of cards are fixed lengthwise at certain distances from each other; these cards or strips consisting of short wires, something resembling the nature of a brush, made of fine iron wire instead of bristles. The wires, however, are not, as in a brush, inserted in bunches, but each stands single, being passed through a tolerable thick piece of leather, and placed so close as to present some hundred points in the space of a square inch; each wire is bent into a form somewhat resembling the staple to a door, its two ends penetrating the leather, and afterwards slightly bent in a general inclined position, in order to meet the work with more effect.

Hides of leather are cut up into strips, varying for different purposes in breadth, from two inches to six inches and upwards. These are passed between iron rollers, adjustable to different distances, and furnished with a sharp cutting edge below, by which, in the passage, the leather strip is shaved off in its thickest parts, and reduced to one uniform thickness throughout; its edges also are very exactly trimmed, to render the whole of one uniform breadth, at least for the same description of card.

These strips thus reduced are passed next to a workman, whose business is to join them end with end into a long length. This is done by placing the end under a strong pressure, leaving about an inch projecting, and this inch is, by means of a sharp broad knife dexterously applied, reduced to a perfect bevel of an inch in length across the breadth, the same having been performed on the end of the piece to which it is to be joined; a very thin solution of fine strong glue, made of acetic acid and isinglass, is applied, the two bevelled parts are placed on each other, the joined part submitted to a strong pressure, which completes the process, and when dry and slightly trimmed, if necessary, the union is formed so perfectly that it is scarcely possible to distinguish the place; a number of such pieces being united together in one length, the leather is fit for the operation of being manufactured into card by means of the Machine. In some Machines the leather is placed vertically, and is carried on upwards as the operation proceeds, but in others it is stretched horizontally. The process is the same in both; but it would require too many figures to illustrate minutely the nature of its action, which is exceedingly complicated and rapid, and displays extraordinary ingenuity. A hank of fine wire is put on a reel, turning horizontally at a short distance from the Machine, and the end of the wire introduced into the frame; the axle being now put in gear, the wire is carried forward about an inch, and is at the same time cut off to that length; two side pieces of steel now press on the sides, and bend the wire to the staple form; in the mean time two fine steel points are pushed forward to form two holes in the leather; these are below the two ends of the staple, and immediately they are withdrawn the wire itself is thrust forward into the holes, while a pair of nippers takes hold of the back of the staple and gives it that slight bend we have before described. The whole of these operations are performed in rather less than half a second, a slight adjustment takes place sideways after each, and thus the process is carried on till the card is completed.

It has been stated that the several operations of drawing on the wire, cutting it to its proper length, bending it to its proper staple form, piercing the leather belt with the two steel points, withdrawing these, bending the wire in its own plane, and inserting it in the card, are all performed in less than half a second; in fact, the mean action of the Machine is at the rate of 130 insertions per minute, the greatest number being about 150. Taking the mean, 260 holes are pierced in a minute, consequently 15,600 in an hour, and the working hours being eleven per day, each Machine pierces 171,600 holes per day, and consequently works up about half that number of inches of wire, or 85,800 inches. There are one hundred of these Machines in the Manufactory of Mr. Dyer of Manchester, which we have had the gratification of visiting. These hundred Machines will, therefore, use up 8,580,000 inches of wire per day, or to the amount of about $13\frac{1}{2}$ English miles. The cards being thus formed are fixed with their backs upon the cylinders above described, which of course prevents the wires from coming out. This, however, is done by the parties employing the cards and form no part of the card-making process. These being sent from the latter Manufactory in the state in which they are taken off the Machine above described.

(403.) *Counting Machines*.—Under this head are included several very ingenious contrivances, which are

Machinery.

Quantity of
wire used
in a day.

Counting
Machines.

Manufactures.

adopted for various purposes, and which it may be well to describe in this place. Such Machines are very useful for counting and registering the number of strokes made by a steam engine in a given time; the number of revolutions made by a carriage wheel while passing between two places, and consequently the distance between those places; the number of revolutions made by the wheel of a railway carriage, so that, by knowing the distance, the amount of slips and retrogradation may be ascertained. Thus, also, an account may be kept of the number of foot-passengers through a toll-way, and a like application may be made in various other cases.

Counting Machines for road carriages, or viameter

(404.) *Counting Machine for wheel carriages.*—A very simple and ingenious Machine for measuring the number of revolutions made by a carriage wheel is sold by Mr. Carey in the Strand. It consists only of a brass plate, having a fixed axis or pin placed perpendicularly to its surface, with an endless screw cut on its middle part. On this axis is suspended a small brass frame hanging freely, and which swings below the axis above named. In the frame are two small brass wheels, turning each freely and independently on the same axis, and each cut with teeth on their edges, bevelling towards each other, the one containing 100, and the other 101 teeth. The endless screw on the fixed axis, engaging in the teeth of each of these wheels, drives them in the same direction, every revolution of the carriage wheel moving them one tooth; for the frame being always kept suspended below the axis by its own gravity, the effect will be the same during the revolution of the carriage wheel to which the Machine is fixed, as if the endless screw itself had made one revolution, and consequently the wheels will each be moved forward one tooth.

In 100 revolutions the wheel with 100 teeth will have returned to its original position, but that with 101 teeth will be behind one tooth. In 200 revolutions the first wheel will have again taken its original position, but the second will be two teeth behind, and so on; so that the number of teeth the second wheel is behind the first will be a register of the number of hundreds of revolutions the carriage wheel has made since the carriage started, or since the Machine was set, and the number of revolutions the carriage wheel has made beyond some even hundreds, will be shown by the number of teeth the first wheel has advanced towards a complete revolution. Thus, for example, suppose the index or zero on the second wheel to have fallen back 72 teeth, and that the index or zero of the first wheel has advanced 37 teeth. This will show that the carriage wheel has made 7236 revolutions, and so on for any number of revolutions under 101 times 100, or 10,100, at which number both wheels will have attained their original position. Supposing the carriage wheel to be 12 feet or 4 yards in circumference, the distance the instrument will thus measure is 40,100 yards, or nearly 23 miles. If the distance exceed this, there is a small spring in some of these Machines which enables the experimenter to count one for three such complete revolutions. But this appendage seems unnecessary, and is more commonly omitted. The Machine will of course continue to count on again after the first 10,100 revolutions, exactly as it did at first; and, therefore, unless the distance was so great as to be likely to lead to a mistake of one complete set of 10,100 revolutions, or 23 miles, such appendage as we have spoken of is unnecessary. In a long voyage by a steam vessel some such means is desirable, and is described in a following article. The wheels above

spoken of are but little larger than a half crown, the circular plate which carries the fixed arm or axis is about the size of a common snuff-box lid; the whole is placed in a strong leathern case, with straps for buckling it to one of the spokes of the wheel, and it should be placed as near to the nave as possible, to prevent the suspended frame from acquiring a centrifugal force sufficient to cause it to overcome the force of gravity, which will of course interfere with its accuracy, this depending altogether on the Machine preserving its verticality during the revolution of the wheel.

(405.) *Counting Machine for measuring the number of strokes of a steam engine.*—We have seen a Machine of this kind, we believe the invention of Mr. Watt, which consisted of a series of very light brass wheels and pinions, the wheels having 100 and the pinions ten teeth, so that the motion is reduced from wheel to wheel one-tenth. Thus 10,000 revolutions of the first wheel will give 1000 revolutions to the second, 100 to the third, and 10 to the next. These wheels are fixed in a small box in one line, the pinion of the first wheel acting on the circumference of the second, and the pinion of this on the circumference of the third, and so on for a series of five, six, or seven very light wheels. This box is buckled or otherwise fixed on the beam of the engine, and a short heavy pendulum, resting on the bottom of the box, slides backwards and forwards at every inclination of the beam; this is so constructed that in sliding one way it engages the teeth of the first wheel, and urges it forward one tooth, but in the return stroke it passes back freely, in the next stroke it engages another, and urges on the wheel one other tooth, and so on. The wheels are all graduated, 0, 1, 2, 3, &c. to 9; and at the commencement all the 0's, are at the top of the wheels in a line, and at any time by looking to the figures shown on the upper part of the wheels, the whole number of revolutions will be indicated in their proper figures and values according to the usual numerical notation. The wheels and pinions are very light, so as to offer but little friction and resistance, and the weight sliding on the bottom of the box is of course such as to enable it in its descent to overcome both.

(406.) *Counting Machine for a toll-bar.*—This may of course be constructed on the same principle as the above as far as regards its registering, but requires to be much stronger. Here the rotations depend upon the turnstile, the pivot of which descends below the pavement, and the number of rotations may of course be counted by any system of wheelwork, which, in this case, is locked up. Moreover, it is necessary here to have a fall to prevent the Machine being turned back, and another to prevent its being urged forward more than one tooth for each passenger. This latter fall has a small iron paddle attached to it, which is above the roadway, and when this paddle is up, or the fall down, the turnstile is locked both ways; but when a passenger wants to pass, the toll man treads on the paddle, and raises the fall, which allows the Machine to advance; but the moment the person is through, his foot is removed, and the Machine is again locked. This is the general principle; the manner of carrying it into execution is quite at the pleasure of the constructor. Generally in such cases one Machine must be for passengers going one way, and one for those passing the other.

(407.) *Donkin's counting Machine.*—This Machine, as well as most others used for a similar purpose, depends upon the well-known principle of relative motion, which

Donkin's counting Machine.

Manufac-
tures.

the author observes may be exemplified by the three hands of a clock, in which one is a counter of seconds during the minute, and this last a counter of minutes during the hour, and the third of the hours through the day. The nature of the expedient had recourse to in this case, will, perhaps, be more readily understood by first stating that, in his Machine, ratchet wheels are employed, and that these wheels are moved one tooth at a time, by means of clicks appended to a lever; but instead of this first wheel gradually moving on a second, the second wheel is only moved forward one tooth at every complete revolution of the first wheel, and the third wheel one tooth at every complete revolution of the second wheel, and so on to any extent required. The Machine is a very complete one, but to render it perfectly intelligible a number of figures would be necessary. We must, therefore, be content to refer the reader, who is desirous of fully understanding its construction and the principle of action, to vol. xxxvii. of the *Transactions of the Society of Arts*, where he will find it fully and clearly described.

Roasting
jacks.

(408.) *Jacks for roasting*.—These are well-known domestic Machines, and are of three kinds besides the original form, which is now, we believe, quite obsolete. This was a wheel like a walking crane, of a small kind, in which a particular description of dog, called thereby the *turn-spit* dog, was trained to walk round like a man in a crane, by which means rotation was given to a wheel, which carried a band passing round another wheel on the spit, which was thus also put in rotation.

Smoke
jack.
Pl. xxxi.
Fig. 8

(409.) *Smoke jack*.—This is a very simple substitution for the labour of the dog. It is represented in fig. 8, where A A is the brickwork of the chimney, which is contracted to a circular figure at A A; B is a strong iron bar, placed upon an arch of brickwork over the fire-place, to form a support for the wheelwork of the jack; C is a horizontal wheel placed in the circular funnel A A; it is made of iron plates, with a number of vanes radiating from the centre, each being placed at an angle of about 30° to the plane of the wheel; the heated air which ascends the chimney will strike the vanes and turn the wheel; the lower end of the spindle D, on which the wheel is fixed, has a pinion E fixed on it, and turns a contrate or crown wheel F on the horizontal spindle G; on the other end of this spindle is a pulley H, for an endless chain, which descends to the spit on which the meat is placed; the pulley pinned on the end of the spit is laid in the loop formed by the endless chain, so that this chain at the same time suspends one end of the spit, and gives motion to it; the under pivot of the spindle D is supported in an iron bracket *m*, projecting from the inside of the chimney, and the lower pivot rests on the top of a standard *n*, which also carries one end of the horizontal spindle G; when the chimney requires to be swept, the wheel C is lifted out of its centre, to allow a boy to pass: these jacks are always in motion when the fire is kept up.

Fly jack.
Fig. 9.

(410.) *Common roasting or fly jack*.—The smoke jack, although exceedingly simple in its action, and convenient as regards its substance, is not suitable for any but large families, where there are necessarily large fires and chimneys. In smaller establishments, the fly jack was the more common appendage of a kitchen fire-place, till in its turn it has been nearly superseded by the spring or bottle jack.

The fly jack is represent in fig. 9, where A is the barrel on which the cord for the weight winds; the barrel is not fixed upon the main axis, which is shown by dotted lines. It slips round upon it quite freely in

the direction proper for winding up the weight; but is prevented from turning in the other direction by a ratchet concealed within the barrel near the cog wheel B. The cog wheel B is fixed fast on the main arbor, and its teeth turn a pinion *b* on one end of the arbor C; the other end of this carries a worm wheel, which cannot be seen in the drawing, but its teeth act in the worm cut on the vertical spindle T. On the top of the spindle is the fly wheel D, which regulates the motion of the jack, and prevents the main arbor from turning too fast by the power of the weight. A wooden pulley E is fixed on the main arbor on the outside of the frame for the endless chain *e*, which gives motion to the spit, and the pulley has several grooves to receive chains for two or more spits at the same time. Two legs or standards, I, K, are rivetted to the frame G, to fix the jack against the wall over the fire-place.

The weight for giving motion to the jack is generally suspended by a pair of blocks with two or three sheaves. The end of the line, or fall from the pulleys, is wound on the barrel A, and the weight is usually placed outside the house, and contained in a sort of chimney, to defend the lines of the pulleys from the weather. When pulleys are used, the jack will continue its motion longer without winding, but the weight must be much heavier than if it was simply suspended to the end of the cord.

When the weight is run down, a handle is applied to the square part *s* of the arbor of the barrel A, which projects through the frame H. By turning the handle round, the barrel goes with it, and winds the rope upon its circumference; but as the barrel slips round on the main arbor when the barrel is turned in that direction, the wheel B continues to revolve and carry the spit by the momentum of the fly wheel D, as long as is requisite to wind up the weight.

(411.) *Bottle or spring jack*.—This is an exceedingly neat and ingenious contrivance, and was the subject of a lucrative patent about forty years back. Its name of bottle jack is derived from the figure of its external case, which resembles that of a common wine bottle, and its name spring jack from its being put in motion by the action of a spring. No spit is used in this kind of jack, but the meat is suspended before the fire and the jack keeps it constantly in motion, by turning it round several times with a proper velocity, first in one direction and then in the opposite. The jack is suspended from a projecting sort of gibbet, attached above the fire-place, and which, turning on pivots like a wall crane, is laid back flat against the wall of the chimney when not in use. We are indebted for the following description of this ingenious little Machine to Mr. Farey, as given by him in Brewster's *Encyclopedia*. The jack is represented in plate xxxi. fig. 10, where A is the spiral spring coiled up in a box which is fastened to the frame. The interior end of the spiral spring is connected with the main arbor B, which is supported by the plates R S. On this arbor the wheel C, with its ratchet wheel *z*, is fixed, and turns the small pinion D on the second arbor E; at the end of this arbor the contrate or escape wheel F is fixed; and G is a vertical arbor with two pallets *a* and *b* projecting from it, the one engaging in the teeth on the upper side of the contrate wheel, and when the pallet *a* is not in action, the pallet *b* intercepts the lower teeth of the wheel. This is a crown wheel escapement, such as is used in common watches, and gives motion to the arbor G alternately in a backwards and forwards

Machinery

Bottle jack.
Fig. 10.

Manufac-
tures.

direction. On the lower end of the arbor G a sector *c* is fixed, and is cut into teeth at its circumference, to form a segment or portion of a wheel. It gives motion to the pinion H on the short vertical arbor *d*; and the wheel I is fixed on the same arbor to give motion to the pinion L in the centre of the jack, which is fixed on the vertical arbor *m*, and passes through the bottom plate of the bottle, and has the fly wheel O fixed to it, with the hook P for suspending the meat. The arms of the sector *c* are sufficiently extended to admit the arbor *m* between them. The arbor is sustained by the fixed cock *i*, and is also suspended by a number of small catgut strings going up through the centre of the jack to the top of the neck of the bottle, and attached to the cross pin *r*. These strings take off part of the weight of the meat which is suspended on the hook P, and diminish the friction on its collar. This effect is, also, partly produced by a small spiral wire spring *t* coiled round the arbor, and bearing on the cock *i*.

The spring jack is wound up by the key Q, when applied to the square part *s* of the main arbor; and in the act of winding, the great wheel C is not turned round by the ratchet wheel *z*, because the click fixed to the great wheel slips over the sloping side of the teeth. To prevent the spring from breaking, a pinion *n* is fixed on the end of the main arbor; beyond the plate it works into the wheel O, which turns upon a pin fixed into the side plate S of the frame. When the main arbor has made a sufficient number of revolutions to wind up the spring, the leaves of the pinion *n* come in contact with a part of the wheel O, which has no space in it, and this prevents the arbor being turned any further so as to endanger the breaking of the spring. The maintaining power of the spring, when wound up, gives motion, by the wheel C and pinion E, to the escape wheel F, the upper tooth of which meets with the pallet *a*, and carries it along with it, turning the vertical arbor round upon its pivots. This motion is communicated by means of the sector *c* to the pinion H, and its wheel I, and thence to the sector pinion L and the fly wheel, and consequently to the meat. The use of the wheelwork CHL is to make the meat turn round several times before the tooth of the wheel escapes the pallet *a*, and then the tooth on the under side of the escape wheel meets with the pallet *b*, and turns the vertical arbor G and the fly wheel back again, in a contrary direction to that in which it was before turned by the pallet *a*; because the under side of the escapement wheel is going in a contrary direction to the upper side, and when the under tooth of the wheel escapes from pallet *b*, the pallet *a* comes into action again from pallet *b*; and thus a continuous motion is kept up, first in one direction for a few turns, then in the opposite direction, and so on, till the maintaining power of the spring becomes exhausted, when it must be wound up again by the key. The tube resembling the neck of the bottle is to give length to the catgut strings before mentioned, and which, by their twisting and untwisting, perform nearly the same office as the pendulum spring in a watch, and make the fly wheel return back readily. The bottom *b* of the bottle is screwed to a flanch or projecting rim round the bottom of the bottle; by removing these screws, and taking out the cross pin *r* in the top of the neck which holds the strings, the frame containing the wheelwork may be withdrawn from the case *x x* to be repaired or oiled as occasion may require.

(412.) *Lathe*.—Is a well-known Machine used for turning wood, ivory, metal, &c.; the essential part of which is

a spindle or mandrel turning very truly, and a rest for supporting the cutting tool. The name lathe, or lath, is undoubtedly derived from the original form of the Machine, which consisted of a long lath or pole fixed by one end to the ceiling or wall of the shop, from the other end of which a cord passed over a pulley carrying the mandrel and passed thence to the end of a board or treadle, which, when pressed on by the foot, gave a rotation to the pulley. On raising the foot, the spring of the lath caused an opposite rotation, which was reversed again by the pressure of the foot; so that the lathe in this form worked like a drill, and the cutting of course only took place during each direct rotation. Some such lathes are still to be seen, but the general principle of their action is now a direct and continuous rotation, by means of a strap or band passing over a pulley on the mandrel. This rotation may be communicated from the axle of a steam engine, water-mill, horse-mill, or by hand; and in some one of these ways rotation is given in the larger and more powerful lathes for turning brass, iron, &c., but in the smaller sort of lathes, the rotation is given to the mandrel by means of a band passing round a pulley on the same, and a fly wheel fixed on an axle with a single or double crank worked by the foot of the turner. This is then called a foot lathe.

The lathe is perhaps of all Machines that which assumes the greatest variety of forms, but it may be generally described as consisting of a horizontal part called the bed, which is formed commonly of two parallel bars of hard wood or metal firmly united together, or of a single metal triangular bar. To this bed are attached two upright parts called puppets, the one carrying the mandrel and pulley, which is fixed in its place, and the other carrying the back centre, which is adjustable, sliding between the double bed or on the single bar, to which in either case it is accurately fitted. The purpose of this is to give a second bearing to the piece of wood or metal while turning, when this is of any considerable length, in other cases the single attachment of the piece to the mandrel is sufficient. On the bed also slides the rest for supporting the gouge or other cutting tool, this being adjustable as well with regard to distance as to height and position. The bed itself is either securely screwed or otherwise fixed to two immovable supports, or it forms of itself part of a heavy strong frame, either secured to the floor, or which is so heavy as to be rendered secure by its own weight. Under the bed is an axle with a crank; to the axle is fixed the fly wheel, with a groove for carrying the band which passes also over the pulley on the mandrel, and to the crank is hung an iron bar attached also to the foot-board, and by which motion is communicated to the fly wheel, and hence to the Machine. This general description, and some minutiae not alluded to above, will be understood by reference to pl. xxxii. fig. 1, 2, in which is represented a lathe of a very simple construction; a front elevation is shown in fig. 1, and an end view in fig. 2. S S S, fig. 2, is a cast iron side of a triangular form; the two forming the support of the bed and lathe are seen in fig. 1, two holes in the bottom ledge of fig. 2 are for admitting two iron bolts to unite the bottom of the two sides together, while the bed securely screwed down to the upper part combines the whole into one compact frame. The sides of the lathe are terminated on the upper part by flanches, and each face of the bed has corresponding flanches; these on both parts are well faced on their edges so as to ensure complete contact, and then bolted together with

Machinery

Modern
foot lathe.
Pl. xxxii.
Fig. 1, 2.

Original
form of the
lathe

Manufac-
tures.

proper bolts and nuts. The part *e* which rises above the flanches is also accurately shaped and filed, and against this the beds rest and are bolted and keyed together transversely; the inside and upper face of the two beds being very accurately filed and ground to true parallelism in order to furnish a perfectly smooth and steady support for the back puppet in whatever part of the bed it is necessary to employ it. A bolt with a square head *E* passes through the base of the puppet, and through an iron block under the bed of the lathe, where its end, with a screw cut upon it, is received by a nut, by means of which it may be securely fixed in any place assigned for it, and when necessary to give it a new position the nut is slackened, the puppet slid to its place, when the nut is again tightened and the puppet secured. The motion of the support for the rest *R* is managed nearly in the same way except that the puppet has a descending square block *b* to work between the beds to secure its perfect parallelism, whereas the support for the rest slides only on the face, and may therefore be turned in any direction, but it is fixed to its place after its position is determined exactly as above described for the back puppet. The front puppet is secured in its place the same as the back one, and when a lathe is well made it may, the same as the latter, be slid from one end to the other of the bed without any shake or undue tightness in any part; this is not, however, so necessary, as it remains a fixture when its place is once properly determined.

About half way up the side of the lathe is a square part, *g g*, fig. 2, on which slides another part *h h*, which latter is drilled and tapped for admitting the screw *t* with a steel-pointed end, fig. 1, for carrying the axle, the latter being countersunk at the end for receiving the points of support. By means of the screw *s* this sliding plate may be raised or lowered, and thus the centres brought to exact equal heights; moreover, by this means the band of the lathe may be tightened when it becomes a little slack.

On the square axle *c* is formed a single or double crank for working the lathe by means of the hanging iron bar *v* and foot-board *a*, for giving motion to the lathe already described.

The wheel *w* should be formed of cast iron, and on its rim should be cast a ring of lead; the wheel is first keyed square on the axle, and then its leaden rim turned in its place with three or four grooves of different diameters to correspond with a similar set of grooves on the wheel *w* attached to the mandrel axle, whereby the speed may be changed, but the band remain of its proper degree of tightness, in any two of the opposite grooves in the two wheels. The axle of the mandrel is supported as shown in the figure; viz. the front face of the puppet has a hole very accurately bored through to receive the axle, which is also accurately turned and then case-hardened, as is also the other end, which is countersunk to receive the steel point on the back screw *s'*, and which is so adjusted by the latter as to allow the axle to turn freely but without any shake: on the front end of the mandrel is an external screw *D* for receiving the chuck for holding the piece of wood or other material which is to be turned.

The back centre is differently arranged in different lathes. The method shown in the figure is certainly one of the best. The bar on which the centre is formed is square and rests diagonally in two half-square holes, over which caps are screwed, having also half-square

notches to embrace the upper half of the bar, and by Machinery. means of the nuts on these screws, perfect contact and fitting may be secured without rendering the motion of the bar too difficult. The screw *s''*, which is best left-handed, is fixed to the end of the square bar, and the nut in which it works, having two flanches at its end, falls into a half-round groove in the part marked *V*, which is covered by a similar piece, viz. one having a semicylindrical groove, and screwed down by nuts as described above for the square bar. A handle *h* is fixed to the back flanch by which the nut may be turned round, and as this is prevented by the flanches from advancing on the screw, the screw itself must recede or advance, carrying of course the back centre with it. This is a remarkably neat method, and admits of the most delicate adjustment.

It now only remains to describe the different chucks by which the body to be turned is fixed to the mandrel. These are very numerous, but some of the most simple are described below.

A chuck of wood is commonly used by mathematical instrument makers. It consists simply of a piece of box, or rather there are generally several such pieces about the lathe, having a hole bored in their end and tapped with a screw whereby they may be screwed upon the end of the mandrel, and then they are turned down to such size as to receive upon them any short brass tube on which work is to be performed; this is fitted on very slightly, and is easily removed when the work is completed. In other cases the end of the wooden chuck is turned with an interior cavity to receive any flat circular piece of brass which requires facing; indeed, all the brass work of instrument makers is performed in this way, and every chuck being preserved, the workman, when a new piece of work is presented to him, selects any one of his old chucks which requires the least alteration, and therefore that alteration is of course readily made. When a tube is longer than can be safely trusted to this single support, a plug of box is introduced into the other end and the back centre brought up to it, which is what is called turning between centres.

Sometimes chucks are formed of flat pieces of brass having a thick piece behind tapped and screwed on the mandrel, and having holes through the flat part by which a piece of wood which is to be faced may be screwed. Others are provided with three jaws which can be altogether caused to advance or recede from the centre by turning a screw so as to encompass a piece of work of any dimensions. This method of chucking is employed in forming all kinds of flat or hollow work, as cups, boxes, circular rings, plates, wheels, &c., which are therefore termed chuck-work, but articles of considerable length must be supported at both ends as above stated; generally, however, the fixing requires to be more secure than that above described for facing slight brass tubes. A very common method is to have a metal chuck screwed on the mandrel, having a square hole cut in its end, and the piece to be turned being cut to fit this square hole is driven into it; at the other end is drilled a small hole to receive the back centre, which is adjusted properly to it by the screw in the back puppet. In other cases the spindle has a chuck screwed to it having a conical point; this forms a support for the end of an arm projecting from the chuck, which intercepts a pin or arm fixed on the work, and by this means turns it round with the spindle.

It would be endless to describe the variety of chucks

Manufac-
tures.

Description
of different
locks.

or methods of holding the work adopted in different cases, these depending in a great measure upon the ingenuity of the workman to adapt them to the particular occasions he meets with; those, however, above described are the most common and generally the most convenient.

(413.) *Lock* is a name given to different constructions of mechanism for securing doors, gates, boxes, &c.; it also denotes a part of a canal in inland navigation in which vessels are received in order to be raised or lowered from one level to another; it is also used to denote that part of a musket, pistol, &c. by which the powder is fired, &c. The common door lock is a well-known instrument consisting of a strong bolt, which must be fitted in a proper bed or case affixed to the door. A great deal of art and delicacy are required in forming and varying the wards, springs, bolts, &c. of locks, and in adjusting them to the places where they are to be used, and to the several occasions and situations in which they are to be employed. Those placed on outer doors are called stock locks; on chamber doors, parlour and other inside doors, spring locks, and when these are inserted in the wood, mortise locks; others are called trunk locks, padlocks, &c. The construction of these are well known; it will, therefore, be sufficient here to say, that the principal parts are, first, the main plate, in which is the keyhole, and to this plate are attached the top hook, cross wards, bolt-toe, drawback spring tumbler, pin of the tumbler, and the staples; secondly, the cover plate, carrying the pin, main ward, cross ward, step ward; and thirdly, the pin hole, to which belong the hook ward, main cross ward, shank, bow ward, and bit.

The principle on which all locks depend is the application of a lever to an interior bolt, by means of a communication from without, so that by means of the latter the lever acts upon the bolt, and moves it into a staple or other recess whereby to secure the door or lid from being opened till the bolt is returned to its original situation by the same means as those by which it was first moved forwards. The security of locks, therefore, depends on the number of impediments which can be interposed between the lever or key and the bolt which secures the door, which impediments are called wards, and consist of short projecting pieces of iron with corresponding notches in the key to pass over them; and it is the number and intricacy of these which constitute or distinguish what is called a good lock from a bad one. If the wards do not, however, cover each other so as effectually to preclude the access of all other instruments besides the proper key, an object very difficult to effect, it is still possible for a mechanic of equal skill with the locksmith to open it without the key, and thus to render the door and lock insecure; and hence have sprung a number of ingenious contrivances, in which the above objection to the common lock is in a greater or less degree avoided. It will be impossible for us to enter upon a description of these several inventions, as they are exceedingly numerous, and would require many plates to illustrate their modes of action; we must, therefore, be content with referring the reader to those places where he will find every information that may be required. The volumes of the Society of Arts are very prolific in these kind of instruments, as will be seen by the following references: vol. i. p. 317; vol. ii. p. 187; vol. iii. p. 160; vol. iii. p. 163; vol. xviii. p. 239, 243; vol. xix. p. 290; vol. xxiii. p. 333; vol. xxxviii. p. 111, 205; vol. xxxvi. p. 116. These volumes all contain de-

scriptions of different locks, extremely curious and many of them very useful and ingenious. See also the third and eighth volume of the *Repertory of Arts*, Old Series, and other patent locks in several volumes of the New Series of the same Work. With this multitude of contrivances, most of them extremely ingenious, it is difficult to make a selection; but one amongst the earliest of them claiming particular merit is that invented by Mr. Bramah, and commonly distinguished by the name of its inventor, which must not be passed over.

(414.) *Bramah's lock*.—This is represented in pl. xxxii. fig. 3, 4, 5, 6. Here A represents the bolt fitted to slide on the metal plate B B C, by passing through a hole in the side C, which is turned up, as shown in fig. 5; the other end of the bolt is guided by passing under proper grooves in the lower side of the circular box D D, which is screwed to the plate B to confine the bolt down. It contains the whole mechanism of the lock, consisting of an anterior cylinder or barrel E E shown in the section fig. 5, with its appendages in perspective in fig. 6. This barrel is fitted to turn round within the box D D, the upper end *aa* being received into a cavity exactly fitting it, and the middle encompassed by a circular ring of steel plate *bb*, screwed into the box as shown in fig. 5, and one half shown at *b*, fig. 6. The ring enters a circular groove formed round the barrel, and thus confines it from having any other motion than a rotation on its axis, and this only by the aid of the key, as will be explained. The barrel has a hole through its centre, which is closed at bottom by a circulate plate F, screwed to it, and supporting the central pin G, which occupies the centre of the hole through the barrel; this centre pin guides the key in entering the lock. When the barrel E E is turned round by the key, it shoots the bolt A, by an ingenious contrivance explained in fig 4, an aperture being cut through the plate B B C to exhibit it. The plate F, on the lower end of the barrel E, has a pin *f* projecting from it; this pin enters a curved opening at a small distance from the centre, and therefore describes a circle when the barrel is turned round, cut through the bolt A, as is shown by the curve F in fig. 4. In the position there shown the bolt is withdrawn, and the pin *f* resting against the solid part of the groove, prevents the barrel being turned round any further in the direction from F to *f*; but by the application of the key, the barrel may be turned in the other direction from *f* to F, in which course it passes round in a circular part of the groove, and therefore produces no motion of the bolt A, until the pin *f* strikes the straight part *g* of the groove and acts against it to throw the bolt forwards; and when the barrel has made a complete circuit, and the pin *f* is again come to the same position it had at first, the bolt is shot out as at fig. 3, and the pin is resting in the hollow *b*, which prevents it moving any further in the same direction. When the barrel is turned back again, the pin *f* acts against the notch *i*, and the curved part *k*, of the groove, and withdraws the bolt into the position of fig. 4; now the pin *f*, either when the bolt is shot out or in, is in a right line with the centre of the barrel E, to which it is fixed, and the direction of the bolt's motion. By this means, no force whatever applied to drive back the bolt can have the least tendency to turn the barrel round, and strain the mechanism which prevents its motion, unless the parts are first put into a particular arrangement by the application of the key. The interior mechanism must be explained by fig. 6, in which *l*, *m*, *n* represent small steel sliders, which are fitted

Machinery.

Bramah's
lock.
Pl. xxxii.
Fig. 3, 4, 5, 6

Manufactures.

into proper grooves or slits, made in the substance of the barrel E. Of these there are six in number, arranged round the barrel, and projecting a little from its exterior surface in the small part. These sliders are received in notches *y z* in the fixed steel ring *b b*, before described; and thus effectually detain the barrel at six points from being turned round, except it is first unlocked by the key R being introduced at the keyhole H, and the slider pressed down by it, so as to bring the notches (of which each slider has one, as at *r*, fig. 6) all opposite the steel plate *b b*, and then the barrel may be turned round. When the key is absent, the sliders are raised up by a brass ring *v* sliding on the central pin G and lifted up by a spiral spring *w*. The key has six notches cut in the end of it, as shown at S, which is an end view: each notch in the key includes one of the six sliders *l, m, n*, and the key being forced down into the keyhole H, depresses all the sliders at once, until the projecting leaf *t* of the key stops upon the bottom of the recess *x* cut in the upper edge of the barrel. In this position the sliders are depressed, so that the notch *r* made in each slider comes exactly opposite the steel ring *b b*, and the barrel is at liberty to turn round all the sliders, being by this means removed, or at least relieved from the steel ring, which, as before mentioned, embraces a groove cut round the barrel, but which cannot turn round therein unless the sliders are also moved by the key, so that the notches cut in them coincide with the groove cut round the barrel, and then it can turn freely round. The key, having thus relieved the barrel by being thrust in as far as it can go, obtains a hold of the barrel to turn it round, by the leaf *t* entering the recess *x*, which it exactly fills up, so as to form a continuation of the circular top of the barrel; but as soon as the key is turned round with the barrel a small quantity, its leaf is caught beneath the circular cavity in the top of the box D, and thus the key is prevented from being thrown out by the spiral spring *w*, until it has been turned quite round, having locked or unlocked the bolt; then the leaf of the key coming opposite the enlarged part *z* of fig. 3, of the keyhole H, the spring throws the key out and raises all the sliders, that they may interlock with the steel plate *b b*, and prevent the barrel from turning, unless the key is again put in, (its leaf being opposite the aperture *z* of the keyhole,) and being thrust forwards as far as it will go, the barrel will turn round very easily; and when it has made a complete circuit, the lock is opened, and the key thrown out of the keyhole by the spring.

The security of this ingenious lock from being picked or opened by a false key, depends upon a circumstance not yet mentioned, which is, that the notches in the six sliders are so made, that every one requires to be depressed a different quantity to bring them all at once opposite the steel ring, in which position alone the barrel can be moved. For this reason the six notches in the key are all of different depths, corresponding to the positions of the notches in their respective sliders, and unless each notch in the key is of the proper depth the lock cannot be opened, for any one being too deep, that slider will not be pressed low enough to relieve the barrel, and will hold it fast, though all the others may be correct; on the other hand, any notch not being of sufficient depth, the slider it acts upon will be pressed too far, and in this case the notch in it, having passed by the steel ring, will lock the barrel as effectually as if it was not far enough. Thus this lock admits of an

immense number of combinations: first in the number of the sliders; secondly, the depth of the different notches in the key; and thirdly, the arrangement of these sliders. The combination of these three changes admits such an immense number of varieties of locks, that it never need happen that two locks should be made to open by the same key. Any of Mr. Bramah's locks may be arranged so as to require a new and different key in case the original one should be lost or stolen; for this purpose the lock must be opened, and the sliders taken out and changed into different grooves; a new key must now be made with the grooves of the same depth of the original key, but arranged in a different order, corresponding with the new arrangement of the sliders. The old key will not now open the lock.

To pick a lock of this kind is perhaps impossible; because though the sliders are exposed to the examination of any person, yet no information can be obtained of the depth of each of the sliders required to be depressed, for, unless they are altogether pressed down, the barrel cannot be turned in the least, and without turning it, no guess can be made by pressing any one slider of the depth at which the notch in it will be opposite the steel ring. Another great advantage of these locks is, that, from the circumstance before explained of the bolt having no action to turn the barrel, though the barrel has a great power to shoot the bolt, a strong lock may have but a very small key. For instance, the bolt of the lock in the plate, which is drawn its full size, is of great strength, while the key R is so small that it may always be carried suspended to the watch chain, and then it will not be in danger of being lost or mislaid, as one may happen to lose a key, and thus give opportunity for ill-disposed persons to make a false key from it, unknown to the owner.

(415.) *The puzzle or combination lock.*—This, which acts as a padlock, is another very ingenious contrivance; which is represented in fig. 7, 8, according to the construction of which no key is required to open it, but only a particular combination of letters, whence the denomination of combination lock; and the difficulty of an indifferent person hitting upon the right combination out of the immense number which may be found, has given to it also the name of the puzzle lock; it is, perhaps, known equally well by either term.

Fig. 7 shows the instrument in an unlocked position, the staple A being upon its centre of motion. The lock consists of a number of circular rings of metal placed side by side upon a tube of the same diameter as the inside of the rings, so that all and each can turn round quite freely and independent of each other. Fig. 8 shows the details of the lock on a larger scale, only one of the rings being drawn to make it more clearly understood. B B is the tube on which the rings turn, soldered or otherwise firmly fixed by one of its ends to the end plate C of the lock, which also carries the centre pin *a* of the staple A. The tube B has a groove *l, l* made in its sides for the studs *2, 2* to move in, which studs project from a round bolt E, sliding endways within the tube B; the end *e* of the bolt is formed into a screw, which enters a hole in the end of the plate D, fig. 7, and unites them firmly together. The rings have each a notch in them, as at *3*, of sufficient size for the studs *2* to move in them, placed in a determined position; the staple A is prevented from being lifted up when the lock is fast by the circular pin *b* entering a hole in the end plate D; but if all the rings are turned

Machinery.

Combination or puzzle lock. Pl. xxxii. Fig. 7, 8.

Manufac-
tures.

round to one determined situation, their notches 3 all coincide so as to allow the studs 2, 2 to enter them. which is done by pulling the end plate D out, its bolt E, with its studs, will move endways clear of the pin b, and permit the staple A to be raised up, as in fig. 7; two marks *m m* are made on the edges of the end plates C D, and the letters on the circumference of the rings are brought for a particular word in a line between the said marks, as shown in fig. 7, where the letters form the word lock, when the notches 3 are in a line, and the end plate D can be withdrawn sufficiently to relieve the staple. We will now explain how the word can be altered at the pleasure of the owner. When the lock is in the position fig. 7, turn the plate D round, and it will unscrew from the bolt E, and the rings may be slipped off endways, one by one, by bringing their notches 3 over the studs 2; each of the rings is formed out of two concentric rings 5 and 6, fig. 8, the outer one, 5, having the letters of the alphabet imprinted on its circumference; it has also a number of small notches cut in its inner circle, corresponding in place with the letters on the outside; the inner ring 6, which slides upon the tube B, has a small projection from its outside, which enters any one of the notches in the outer ring; it has also a large notch 3 cut from the inside to allow the studs 2 to pass, and is turned out larger at the back side round the centre, for the studs to turn round in when the lock is fastened.

By this arrangement, whatever letter on the outside of the ring 5 is placed to correspond with the notch 3 in the inner ring 6, must also be placed in a line with the marks *m m*, fig. 7, to enable the lock to be opened; for if any one of the rings is not placed with the proper letter opposite the marks, the corresponding stud 2 will not enter its notch 3, and, consequently, the bolt E cannot be withdrawn so as to relieve the staple A.

The different combinations that a lock of the above description will admit of are immense; since each of the rings admit of twenty-four positions with respect to the notch 3 only. The owner of such a lock must be careful not to forget the opening word he last placed it at, as in such case it would require to be broken open by force, since there is no means of discovering the word except when the lock is open.

We cannot pursue this subject to a great length, but must refer the reader who wishes to learn more of the nature of these ingenious constructions to the volumes above quoted.

Bentham's
planing
Machine.

(416.) *Planing Machine for wood.*—After the operation of sawing there is no process more laborious, or on which more time is consumed by carpenters, millwrights, wheelwrights, and other workers in wood, than that of planing; and, accordingly, attempts have at different times been made to perform this mechanical process, in which little skill is required, by Machinery. The first attempt, we believe, was made by General Bentham, who, in 1791, took out a patent for a method of effecting this object, but notwithstanding the ingenuity of the inventor, it was not attended with all the advantages he had anticipated; indeed, the principal object of this patent was to exonerate the workman, not from the labour, but from the charge he had of his tool in the operation of planing, by so adjusting the cutting iron that it could not but perform the operation intended without requiring any of the skill of the workman, and thereby rendering a common labourer as serviceable as the best joiner for this purpose.

VOL. VII.

With this view the plane was made the full width of the board, and on each side of it were fixed fillets which projected below the face of the plane, just as much as it was intended to reduce the board in thickness, serving thereby to guide the plane sideways, and to gauge the thickness; because when the boards are reduced to this amount, the fillets will rest on the bench or which the boards are placed, and will no longer apply its edge to the plane. The plane was kept down by its own or by additional weights when necessary, which latter were so contrived as to be capable of having their position shifted during the time it was making the stroke, the pressure at first acting forwards, and lastly on the hinder part to prevent the fore end dipping down the instant it leaves the board. By another contrivance the plane was lifted up on its return, so as to clear the cutting edge from the wood. This was effected by a piece of wood which acted as a handle to the plane, and to which the power was applied: it was placed with this view upon an axle extending across the width of the plane, and carrying on each side a short lever provided with rollers at their extremities; the handle projected upwards from the plane, which being forced forward by it, assumed an inclined position, as also did the short levers, so that their rollers then rose above the cheeks of the plane; but when the latter was drawn back into an erect position, the levers moving with it, their rollers projected beneath the cheeks of the plane, and raised it off the bench, the plane being supported by them on its return.

The bench for supporting the board during the operation had also a peculiarity in its construction which it may be proper to describe. In cases where the boards to be planed were winding and irregular on the lower side, so that they could not lie flat upon the bench, it was provided with two cheeks which might be brought close to the edges of the board, so as to hold the latter steadily between them, the cheeks having been furnished with two or more rows of flat teeth to penetrate the wood, and to retain it in its place. These sides were so contrived as to rise and fall with the bench to accommodate the whole to different thicknesses of board. If a very thin board had to be planed, it would, of course, be liable to spring up to the iron, so as to be reduced after the plane came to rest with its cheeks upon the bench; to avoid this the edges of the board were held by the sides of the bench above mentioned, but as it would still be liable to spring up on its middle part, heavy rollers, or rollers loaded with weights, were fitted in apertures made in the plane, as near as possible to the cutting edge, which answered the intended purpose of keeping the plane down close to the bench. For planing pieces of greater thickness at one end than at the other, the cheeks of the plane were supported upon wooden rollers laid on the bench on each side the wood, as much thicker at one end as the board at the other; therefore, when the plane had reduced the wood, the cheeks came to their bearing on these rollers, and caused it to move, not parallel to the bench, but inclined according to the degree in which it was thicker at one end than at the other. In like manner, by using them of different thicknesses at the different sides, the boards might be made feather-edged.

This Machine might have been put in motion by Machinery, but we believe it never was worked usefully but by hand. In either case, however, as all the adjustments were made and regulated by the Machinery, none of the skill of the workman was required in the process.

2 T

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tures.

Bramah's
planing
Machine.

(417.) The next great improvement in planing Machines was made by Mr. J. Bramah of Pimlico, who, in 1802, took out a patent for Machinery, for the purpose of producing straight, smooth, parallel surfaces, and curvilinear surfaces on wood and other materials requiring accuracy, in a manner much more expeditious than can be performed by the use of axes, saws, planes, and other cutting instruments used *by hand*. The description of this Machinery is very explicit, although not very elegant, as given in the specification; we shall, however, give it in the author's words, as reported in vol. ii. of the new series of the *Repertory of Arts*.

"The principal parts of my invention are as follows: that is to say, to shorten and reduce manual labour, and the consequent expenses which attend it, by producing the effects stated in my patent by the use of Machinery, which may be worked by animal, elementary, or manual force; and which said effects are to produce straight, true, smooth, and parallel surfaces in the preparation of all the component parts of work, consisting of wood, ivory, horn, stone, metals, or any other sort of materials or composition usually prepared, and render them true and fit for use by means of edge tools of every description. I do not rest the merits of this my said invention on any novelty in the general principle of the Machinery I employ, because the public benefit I propose will rather depend on new effects, produced by a new application of principles already known, and Machinery already in use for other purposes in various branches of British Manufacture. This Machinery, and the new manner of using it, with some improvements in the construction, together with sundry tools and appendages never in use before, are particularly described and explained here under.

"I mean to use and apply for the purposes above stated, every kind of edge tool or cutter already known, either in their present shape, or with such variations and improvements as the variety of operations I may encounter may severally call for. But the tools, instead of being applied by hand, as usual, I fix, as judgment may direct, on frames driven by Machinery, some of which frames I move in a rotary direction round an upright shaft, and others having their shaft lying in a horizontal position, like a common lathe for turning wood, &c. In other instances I fix these tools, cutters, &c., on frames which slide in stationed grooves or otherwise, and, like the former, calculated for connection with, and to be driven by Machinery, all of which are hereafter further explained and particularized.

"The principal points on which the merits of the invention rest are the following. First, I cause the materials meant to be wrought true and perfect as above described, to slide into contact with the tool, instead of the tool being carried by the hand over the work, in the usual way.

Secondly, I make the tool, of whatsoever cutting kind it be, to traverse across the work in a square or oblique direction, except in some cases where it may be necessary to fix the tool or cutter in an immovable station, and cause the work to fall in contact with it by a motion, confining it so to do, similar to the operations performed on a drawing bench.

"Thirdly, in some cases I use, instead of common saws, axes, planes, chisels, and other such instruments usually applied by hand, cutters, knives, shaves, planes, and the like, variously, as the nature of the work may render necessary; some in form of bent knives, spoke shaves, or deep cutting gauges, similar to those used by

turners for cutting off the roughest part. I also apply Machinery. planes of various shapes and construction, as the work may require, to follow the former in succession, under the same operation; and which latter I call finishers.

"Fourthly, these cutters, knives, &c., I fix on frames of wood or metal properly contrived for their reception, and from which they may be easily detached for the purpose of sharpening and the like: these I call cutter frames. These cutter frames I move in cases like those on which the saws are fixed in a sawing mill, and sometimes to reciprocate in a horizontal direction, confined and stationed by grooves or otherwise, as may be found best calculated to answer the several works intended. In other instances, and which, I apprehend, will generally have the preference, I fix cutter frames on a rotary upright shaft, turning on a step, and carrying the frame round in a direction similar to the upper millstone; and sometimes I cause the frames to turn on a horizontal shaft, just resembling the mandrel of a common turning lathe, or those Machines used for cutting logwood, &c., for the dyer's uses. When these frames are mounted in any of the foregoing directions for cutting, planes, &c., are fixed so as to fall successively in contact with the wood or other materials to be cut, so that the cutter or tool calculated to take the rough and hilly part operates the first, and those that follow must be so regulated as to reduce the material down to the line intended for the surface. These cutter frames must also have the property of being regulated by a screw or otherwise, so as to approach nearer the work, or recede at pleasure, in order that a deeper or shallower cut may be taken at discretion, or that the Machine may repeat its action without raising or depressing the materials on which they act. The manner of thus regulating the cutter frames, when on an upright shaft, is particularly described below. These cutter frames may be made of any magnitude and dimensions the work requires, only observing to make the diameter of those on the rotary plane so as to exceed twice the width of the materials to be cut, as the said materials must slide so as to pass the shaft on which the cutter frames revolve, when on the upright principle.

"Fifthly, When I use upright shafts for the purpose of carrying the cutter frame as above described, I do not mean that the lower end or point of such shafts shall come in contact with, or rest on, the bottom of the step or box in which they stand; neither do I mean that such said shafts shall rest or turn on any stationed unaltered point at rest, but the pivot or lower point of the shaft shall actually rest and turn on a fluid body, such as oil, or any other fluid proper for that purpose, a considerable portion of which is always to be kept between the lower point of the shaft and the bottom of the step in which it works. The said shafts may be either raised or depressed at pleasure to any required altitude, by means of a greater or less quantity of the said fluid being confined, as aforesaid, between the end of the shaft and the bottom of the step. This device I deem of great consequence in the fabrication of all kinds of Machinery, where massy and heavy loaded upright shafts are used; and I perform it in the following manner; that is to say, the lower part of the shaft must be turned perfectly smooth and cylindrical, to a height something above the greatest distance or length the shaft will ever be required to be raised or depressed when in use. This part of the shaft I immerse or drop into a hollow cylinder, which fits its circumference near enough to allow free

Manufac-
tures.

dom of motion, but sufficiently fitted to prevent shake. This cylinder I call the step cylinder, which must be of a length nearly equal to that of the cylindrical part of the shaft above mentioned, so that when the point of the shaft rests upon the bottom of the cylinder, the parallel or cylindrical part may be something above the top or upper end of the step cylinder. In the upper end of this step cylinder I make a stuffing box, by means of a double cupped leather or other materials surrounding the cylindrical part of the shaft, in such a way as will cause the junction, when the shaft is passed through it, to remain water tight under any pressure that may be felt from the efforts of the fluid, retained as above mentioned, to make its escape upwards through this part which I have called the stuffing box, when the shaft with all its load is passed through it, and immersed in the cylinder below. When this is done, the injection pipe of a small forcing pump, similar to those I use in my patent Press, must form a junction with the step cylinder in some part below the stuffing box; then the pump being worked, the oil or other fluid injected by it will, by pressing in all directions, cause the shaft to be raised from the rest on the bottom of the cylinder, and to be slid up through the stuffing box just the same as the piston of my patent Press; and by this means the shaft with all its incumbrance, and whatever may be its weight, may be raised to any given point at pleasure, and at the same time it will be left resting on the fluid under it, whatever the quantity or thickness of such fluid may be between its points and the bottom of the step cylinder. By this means the shaft, with all its incumbent load as aforesaid, should it even amount to hundreds or thousands of tons, can be easily raised and depressed to any required point at pleasure, by the alternate injection or discharge of the fluid used, exactly the same as performed by my Patent press as aforesaid; and at the same time all friction will be avoided, except that of the stuffing box, which will be comparatively trifling to that which would result from the resting of such a shaft on the bottom of the step in the usual way. Thus will be gained the properties above stated; and in addition thereto I think it may be inferred, that provided the stuffing box is kept perfectly fluid tight, such a shaft thus buoyed up by and turning in a proper fluid, may continue working for years, or perhaps hundreds of years, without a fresh supply of oil, or whatever other fluid substance is found the most proper to apply.

"Sixthly, the material that is to be cut and made true must be firmly fixed on a platform or frame, made to slide with perfect truth, either on wheels or in grooves, &c., similar to those frames in a saw-mill, on which the timber is carried to the saws. These frames must be moved in a steady, progressive manner, as the cutter frame turns round either by the same power which moves the latter, or otherwise as may be found to answer best in practice. This motion also must be under the power of a regulator; so that the motion of the sliding frame may be properly adjusted according to the nature of the work. The motion of the cutter frames must also be under the control of a regulator; so that the velocity of the tool in passing over the work may be made quicker or slower, as such work may respectively require, to cause the cutter to act properly and to the best advantage.

"Seventhly, I regulate the motions of both these parts of the apparatus as aforementioned, by means of a new invention, which I call a universal regulator of velocity,

and which is composed as follows; viz. I take any number of cog wheels, of different diameters, with teeth, that will exactly fit each other through the whole, suppose ten or any other number, but for example say ten, the smallest of which shall not exceed one inch in diameter, and the largest, suppose ten inches in diameter, and all the rest to mount by regular gradations in their diameters from one to ten. I fix these ten wheels fast and immovable, on an axis perfectly true, so as to form a cone of wheels. I then take ten other wheels, exactly the same in all respects as the former, and fix them on another axis also, perfectly true, and the wheels in conical gradation also; but these latter wheels I do not fix fast on their axis, like the former, but leave them all loose so as to turn upon the said axis, contrary to the former which are fixed. All these latter wheels I have the power of locking by a pin, or otherwise, so that I can at discretion lock or set fast any single wheel at pleasure. I then place the two axes parallel to each other, with the wheels which form the two cones, as above described, in reverse position, so that the large wheel at the one end of the cone may lock its teeth into the smallest one in the cone opposite, and likewise *vice versa*. Then suppose the axis on which the wheels are permanently fixed to be turned about, all the wheels on the other axis will be carried round with an equal velocity with the former, but their axis will not move. Then lock the longest wheel on the loose axis, and by turning about the fastened axis as before, it must make ten revolutions while the opposite perform but one; then by unlocking the longest wheel and locking the smallest one at the contrary end of the cone in its stead, and turning as before, the fastened axis will then turn the opposite ten times, while itself only revolves once. Thus the axes or shafts of these cones, or conical combination of wheels, may turn each other reciprocally, as one to ten, and as ten to one, which collectively produces a change in velocity under a uniform action of the *primum mobile*, as ten to a hundred: for when the small wheel on the loose axis is locked, and the fast one makes ten revolutions, the former will have one hundred. And by adding to the number of these wheels and extending the cones, which may be done *ad infinitum*, velocity may be likewise infinitely varied by this simple contrivance: A may turn B with a speed equal to thousands or millions of times its own motion; and by changing a pin and locking a different wheel, as above described, B will turn A in the same proportion, and their power be *transferred to each, in a proportion reciprocally as their velocities*. Here is, then, a universal regulator at once for both power and velocity. In some instances I produce a like effect by the same necessary number of wheels, made to correspond in conical order, but instead of being all constantly mounted on the axes or shafts, as above described, they will reciprocally be changed from one axis to the other in single pairs, matched according to the speed or power wanted, just as in the former instance. This method will have in all respects the same effect, but is not so convenient as when the wheels are all fixed, &c.

"Eighthly, when spherical surfaces are to be produced perfectly true, and equidistant from their centres in all directions, I use a tool or cutter, of a proper shape, according to the nature of the materials to be cut. This tool must be fixed on a cutter frame, fastened to the rest of any common lathe, so as to present its point exactly to a line drawn through the centre of the man-

Machinery

Manufac-
tures.

drel of the lathe horizontally, and the said frame on which the cutter is fixed must have the capacity of drawing out, at pleasure, to any required distance, to accommodate the diameter of the sphere to be cut or turned true. This cutter frame must be likewise made to turn upon a centre or pin, very firm and steadily fixed on the rest above mentioned, so as to enable the cutter to be turned by its frame round a centre exactly perpendicular to the centre of the lathe or line before mentioned, by which the altitude of the tool's point is to be regulated; when this is done, and the wood or other material is fixed on the lathe in the usual way, the cutter frame must be drawn nearer or further distant from the centre on which it turns, to accommodate the diameter, just the same as the common rest. If the materials be rough, and require to be reduced to a spherical form by gradations, the work may be repeatedly gone over by the cutter before it reaches the diameter proposed. By this simple apparatus the difficulty of turning perfect spheres is overcome; as it must be obvious to any person of the most ordinary capacity in Mechanics, that while the work is turning in the lathe in a vertical direction, and the tool or cutter is by the hand or otherwise turned at the same time, in a perfectly horizontal direction round a centre, opposite to the actual centre of the sphere, the point of the tool or cutter must, of necessity, generate or turn a perfect sphere, true in all directions, without the smallest attention or assistance from the use of the instrument. I mention here the application of the cutter frame to a common lathe, conceiving it will, by such an explanation, be more familiarly understood without a drawing; but, by this method, spheres of any practical magnitude may be cut with perfect ease and certainty.

"Ninthly, when concave surfaces are to be produced perfectly true, smooth, and equidistant from their respective spherical centres, the work is fixed on a Machine, the same in all respects as the common turning lathe, as in the instance last referred to; I then fix a tool or cutter on a centre, exactly in a line, both perpendicular to and on a level with the exact centre of the shaft or mandrel on which the work revolves: and which cutter or tool projects to the required radial distance with its point, so that when the work goes round by the revolution of the lathe, the tool or cutter at the same time revolving round its centre, a spherical concave will be generated and produced by the fluxion of its point, as in the instance of the convex sphere.

"Tenthly, I convert solid wood, or other materials, into a thin concave shell, similar to a dish; I cut them alternately out of each other, beginning at the smallest, by means of another tool or cutter, likewise moving on a stationed centre as before, exactly on a level with and perpendicularly true with the centre of the mandrel or shaft of the Machine on which the work is fixed. This tool or cutter is made at its exterior point or cutting end of such a shape as best suits the nature of the work; and its shank or stem is bent to the exact circle the concave is meant to be: it is then fixed on an arm or frame calculated to receive others of different circles according to the work; in fact, the same frame may be used which is above described to hold the tool for cutting spheres, either of the concave or convex kind. The tool must be fixed on this frame or arm, as above mentioned, at such a radial distance from the centre on which the frame or arm turns, so as to form a quadrant, with one leg turning on its centre and the tool forming

the periphery with its cutting point projecting to the line of the deficient leg. Before this tool begins its action, a common rest must be applied close to the face of the work, in order to support the tool when it begins its cut, and on which rest the tool will slide till its point proceeds under the control of the centre on which its frame is fixed, until it reaches the horizontal line of the lathe's centre, when the part cut off, or the inner dish, will fall from the stock, and leave the rest for the operation of another tool of a larger circle. Thus the operation may be repeated till the whole lump is converted according to the intentions of the owner."

(418.) *Planing Machine in the Royal Arsenal, Woolwich.*—According to views laid down in the above specification, Mr. Bramah constructed the Machine employed in his own workshop, but that which we are about to describe being a subsequent construction, differs in many essential parts from the former, and is perhaps as perfect as such a Machine can be made. In the carriage department of the Royal Arsenal, where all the gun carriages, both for the artillery and for the marine, are constructed, there is a great deal of very heavy planing, and if in any establishment such a Machine can be advantageously employed, it is in this. The Machine is represented in plate xxxiii., where fig. 1 and 2 show the elevation and plan, and the other figures such parts as require particular description.

Referring to fig. 1, *a a* is a solid bed of brick and stonework, intended to form a foundation for the Machine, and rising one foot above the ground-floor; *b b* are iron slides fixed firmly to the foundation stones, shown in fig. 2, and inclining half an inch from the horizontal line in the whole length (forty feet) towards *B*; *c c*, *d d*, are the movable carriages, on which the wood *e e*, intended to be planed, is supported; *f f* is the cylinder of an hydraulic or hydrostatic Press, having two entrance pipes *g* and *h*, one at each extremity. The piston rod of this Press is furnished with a rack *i i*, which works a pinion *j*, under and attached to the wheel *w*. Round this wheel and the three smaller wheels *W W W* passes an endless chain, which may be stretched at pleasure, so as to keep it to its work by means of a screw attached to the movable slider carrying the centre wheel. The cylinder containing the condensed or compressed water is in an adjacent room, and therefore not shown in the drawing; the water is, however, conveyed by pipes to the cocks at *k*, which are so contrived as to admit of the compressed fluid being directed through the pipes *g* or *h*, and such that, when the pipe *g*, for example, is opened to the compression, the pipe *h* is made to communicate with the waste; hence when the water enters at *g*, the piston is urged forwards, and the rack working on the pinion, under the wheel *w*, gives motion to the chain and to the carriages attached to it. This brings the carriages *c c* from the extremity *A* towards *B*, and at the same time, the carriage *d d* towards *A*, at least when this latter is also attached to the chain, but generally only one carriage is attached at a time. The carriage *c c* having been advanced as far as requisite towards *B*, the cock at *k* is turned, the pipe *g* is opened to the waste water, and the pipe *h* to the compression, the carriage then turns towards *A*, when the pipe *h* opens to the water and the pipe *g* to compression, and the carriage again returns.

The means employed to give motion to the carriage being thus explained, we must now endeavour to illustrate the operation of the planing wheel. In the eleva-

Machinery.

Planing
Machine in
the Royal
Arsenal,
Woolwich.
Pl. xxxiii.
Fig. 1, 2, 3, 4.

Manufac-
tures.

tion fig. 1, C C is a strong vertical iron spindle, carrying the horizontal iron wheel H H, which in its circumference or rim is pierced with thirty holes, furnished with twenty-eight gouges or cutters and two planes. This wheel, which is preserved horizontally by twelve braces, *m l, m l*, is put in rotation by the wheelwork shown in the figure, at the rate of about ninety revolutions per minute, F F being the principal shaft or axle connected with a steam engine in an adjacent apartment. D D, fig. 1, are the sections of two principal beams across the workshop; E E, E E, two uprights, or pillars, which with the woodwork shown above, and two other pillars not shown, serve to give stability to the Machine, and to support the stout wire guard *n n n n*, intended to protect bystanders from accident, to which they might be otherwise exposed.

In the general character of this Machine, its operation is pretty obvious; while the carriages are passing from one end of the slider to the other, by the action of the hydraulic Press above explained, the wheel is put in rotation, and so adjusted by means of another hydraulic Press, that the gouges and planers attached to the horizontal wheel H H just catch the surface of the piece of wood *e e* in its passage under it. The gouges being arranged in its rim, at different distances from the centre, and these being followed by the two planing irons in the rotation, render the surface thus exposed to the operation beautifully plane and smooth.

It is stated above, that not only the carriages are passed backwards and forwards under the cutter by means of hydraulic pressure, but also that the wheel itself is sustained and adjusted by the same means. The general principle of this action may be sufficiently understood from the figures in the plate referred to, but the apparatus for changing the direction of the motion being very small on the scale of the drawing, may require a few words of additional illustration. This is effected by what is called a four-way cock, shown on a larger scale in fig. 3. Here A B D C represent the part shown at fig. 1 and fig. 2; *h* is an opening into the pipe leading to the end *h* of the cylinder or hydraulic press, and *g* is another pipe leading to the end *g* of the same cylinder; *a* is an opening into the pipe leading to the vessel in which the compressed air and water is contained, and *b* an opening into the pipe leading to the waste or open atmosphere, and therefore only exposed to the pressure of the latter, whereas the water in the pipe sustains a pressure of fourteen hundred pounds per square inch. P is a circular plug having within it two curved ways, which may be made to unite at pleasure either *h* with *b*, and *g* with *a*, as represented in the figure, or by turning a quarter round they will unite *h* with *a*, and *g* with *b*. In the former case the piston will be urged from *g* towards *h*, fig. 2, and in the latter from *h* towards *g*. The motion of this plug is under the control of the workman superintending, by means of the handle shown at *k*. To effect this change, a motion amounting to a quadrant or 90° is necessary, but if a motion of the handle is made of only half a quadrant, then the ways are all shut and the Machine remains stationary.

The method of raising the cutting wheel and spindle is as nearly as possible the same, except that here it is only necessary to connect alternately the bottom of the vertical cylinder with the charge pipe and waste; therefore in this case the central plug has but one curved way, which may be turned so as to connect the bottom of the cylinder with the charge pipe when the wheel and

cutters are to be raised, or with the waste when it is to be lowered, or it may be placed intermediately between the two positions, preserving the wheel stationary as during the time the timber is under the planing operation. Fig. 4 shows the method of fixing the timber to the carriages.

(419.) *Machine for planing iron.*—Formerly, when the construction of Machines was less common, and their action less accurate than at present, the only method of obtaining a level metallic face on iron, was by first chipping it with a cold chisel to a tolerably level plane, and then completing the operation by the file; but since the extraordinary employment of Machinery in this Country, that process has been found too slow for the rapidity with which Machines have been required, and too uncertain and imperfect for the due execution of the operations they have been intended to perform. Accordingly many attempts have been made to supersede the above laborious manual process by the substitution of Machinery, and different methods of effecting this desirable object have been proposed. In some of these the cutters intended to form the surface have been made to revolve, while the plate whose surface was to be formed moved slowly under them, something after the manner of the wood planing Machine last described. Generally, however, the motion has been rectilinear; in one case the cutter or plane having been made to pass over the body on which the operation is to be performed, and in others the plane has remained stationary while the body passed beneath.

The latter is now most commonly adopted. At Messrs. Sharp and Roberts's manufactory at Manchester, there are several such Machines, one of which, on a very large scale, is perhaps the most perfect in the Kingdom. When we saw it at work, it was planing the face of a large lathe bed, of fifteen feet length, and with a face of ten inches. The work was nearly completed, and nothing could exceed the beautiful surface that had been obtained.

The planing tool is fixed in a frame supported by a strong upright cast iron frame, the former being adjustable both laterally and vertically to bring it to its work; it may also be inclined at any angle to enable it to plane any inclined surface, and being accurately graduated, the required bevel is immediately set on without difficulty or loss of time. The frame also has a motion whereby at the end of the stroke it rises and allows the carriage bearing the body to be planed to pass back free of the cutter. In this way the largest surfaces are planed by the assistance of a single workman to adjust the cutter after every stroke; but even the amount of this motion is so much under the dominion of the Machine itself, that it is nearly impossible for him to commit any error. The apparent ease with which shaving after shaving is stripped away, is to a person not accustomed to witness such operations truly wonderful, and never fails to excite their surprise.

Besides this large planing Machine, there are several smaller ones in the same establishment, whereby the use of the chisel and file is almost wholly superseded.

The above Machines are obviously only calculated for heavy strong work; in more delicate operations, whether for planing wood or metal, a Machine has been invented and constructed by Mr. Clements, which is considered to be a very perfect piece of workmanship, and we are sorry that the number of figures requisite for its full illustration is so great that we are under the necessity of passing it over without description. We can

Machinery.
Machine
for planing
iron.

Planing
Machine by
Clements.

Manufac-
tures.

General
remarks on
the nature
of pressure.

only refer the reader, who is desirous of being thoroughly informed respecting its mechanism, to the *Transactions of the Society of Arts*, part i. vol xlix.

(420.) *Of Presses and Machines acting by pressure.*—As presses assume a great variety of forms in different mechanical processes, and as these are commonly better described in connection with the Machine or process in which they occur, we shall only take in this place a general view of the nature of pressure, and the description of one or two Presses not elsewhere noticed, and for the rest shall merely refer to those articles where any particular application has been already explained. The objects attained by pressure are to compress bodies into small space, as in the Packing Press; to augment their dimensions in a particular direction, as in the Rolling Presses, or Rolling Mills for iron, lead, copper, &c.; to divide the substance of bodies, either wholly or partially, as in cutting the blanks, and afterwards impressing certain figures, as in coining; to reduce them to more minute portions, as in stamping ores and similar processes. The Machines by which these several operations are effected may be considered as different descriptions of Presses; but custom has limited the term Press only to some of them, and generally to those which act by means of a screw, and to the Hydraulic Press invented by Mr. Bramah.

The screw of the Press is generally turned by a lever, for without this assistance, however powerful the Press might be, the friction of the screw, which is always very great, would render it almost useless; but this friction being once overcome, it is found of great convenience, being generally sufficient to furnish its own pail, or to prevent any retrograding, retaining thus the pressure acquired without the necessity of any other mechanical means. When great force is required, the screw, that is, the threads are made as close as possible consistent with their strength; but in such cases a double screw, hereafter described, may be advantageously employed. The screw of a Printing Press or of a Stamping Press is, on the contrary, very open, and it is caused to descend with considerable velocity and momentum, the handle being loaded with a weight for that purpose. Wherever a force is so employed as to produce an impulse which acts on any body, the momentum, which is the result of the action of the force for a certain time, is usually much more powerful than the simple pressure; but the degree of its efficacy depends on the degree of compressibility of its substance. If a heavy body fall from a certain height, so as to acquire a momentum, in consequence of the force of Gravity, it will ultimately exert upon the substance on which it falls a force about as much greater than its weight, as the space through which the substance struck is depressed, by means of the impulse, is less than twice the height from which the body has fallen, and unless the body is very compressible, or the height very small, this force must be incomparably greater than the pressure of the weight only: and in this way we must account for the effect of the Presses used in coining, in button making, and other such processes. See those articles.

In a Printing Press it will be seen that a single heavy roller is sometimes made to pass over the paper, when it has been laid on the types, and since the whole action of such a roller is confined to a small part at any one time, it is found to exert sufficient force, and to perform its work more accurately than the old common Printing Press. The Mangle for domestic purposes, although

not commonly thus classed, is amongst the latter description of Presses, and so also, indeed, is the cylindrical and common Calender, the Copper-plate Press, and the Copying Press. Again, the Sugar-mill, although not commonly spoken of under the denomination of a Press, is, in fact, a Machine of this class, the pressure being exerted between the rollers as the cane passes through; so also the Rolling Mills for lead, iron, and other metals; (see those articles;) and even wiredrawing is, by Dr. Young, included in this class of operations, the force originally employed in the direction of extension being much less than the lateral compression brought on by means of the conical apertures through which the wire is successively drawn.

Of these different Presses and forms of pressure, we shall here, however, confine our description to such only as are, in the common language of the Arts, known under the name of Presses, and of those only, to such as are not elsewhere described in this Work.

(421.) *Common screw packing Press.*—All these are of nearly the same kind, having generally a single screw, formed either of wood or iron, which at its lower end has an enlarged head, with holes through it for the reception of the end of the lever employed to turn the screw, the thread of which is fitted through a nut fixed fast in the head of the wood or iron frame of the Press. The frame consists of a lower bed or horizontal piece, on which the goods to be packed, or the matters to be compressed, are laid, two upright cheeks being firmly united with it, and supporting the head or upper horizontal piece of the Press in which the nut of the screw is fixed; the lower point of the screw is united with the follower or moving bed of the Press, and this rests upon the substance to be pressed, while the power of the screw forces it down upon it, and where it is retained after every effort by the natural friction of the screw as above stated. See fig. 1, plate xxxiv. The screws for Presses were formerly made of wood with sharp threads, that is, the worm of the screw, if cut across, would make a triangular section, the base abutting against the cylinder of the screw; but in this way it was necessary to have threads very coarse to give them sufficient strength, and, consequently, the power of the screw was not so great as in modern Presses, where the screw is formed of iron, as their threads need not be one-third the thickness of those of wooden screws; the latter are, however, still used where great strength is not required.

We have said that commonly the Screw Press consists of one screw and two fixed cheeks; but there is another kind of Press in which two screws are immovably fixed in the lower board or bed, and passing through holes in the upper board have nuts upon them, which being turned by a lever draw the two boards together and exert a pressure upon any thing placed between them. These screws sometimes pass through the upper board and are tapped into the lower one; in which case the screws themselves are turned round by a lever put through their heads instead of turning the nuts. Presses of this kind, when accurately made, have a communication of wheelwork from one screw to the other, so that both may turn accurately together, and cause the two boards of the Press to advance parallel to each other.

In 1797, Mr. John Pack obtained a reward from the Society of Arts for a very ingenious Packing Press of this kind. This Machine consists of two very strong horizontal beams at the top and bottom of the Press. These are united by two iron screws, which stand in a

Machinery.

Packing
Press with
a single
screw.
Pl. xxxiv
Fig. 1.

Packing
Press with
double
screw.

Manufac-
tures.

vertical position, and, therefore, serve as cheeks to the Press. The follower of this Press is a very strong horizontal beam, having two nuts fitted into it at its ends. These nuts act upon the threads of the two vertical screws; and, therefore, it is plain when they are turned round, the follower will rise and fall upon them. The nuts are so fitted into the follower as to admit of a circular motion round the screws, but are not permitted to rise or fall without the follower, because they have a circular ring or projection in the middle of their length, which is fitted into proper receptacles in the woodwork. To give them motion, the edges of the circular rings are cut into cogs or teeth, and are turned by means of an endless screw for each, situated at the opposite ends of a horizontal spindle, which revolves in bearings attached to the follower of the Press. The spindle has a winch at each end, by turning which the two endless screws act upon the wheels or teeth of the nuts; and by thus causing them to turn round with equal velocities, raises or depresses the follower, always parallel to itself, and also to the head and bottom bed.

The great utility of this Press consists in its being capable of packing two sets of bales at once; thus answering the purpose of two Presses, and with more expedition. It is placed upon the floor of the warehouse in which the packing is to be performed, and behind it a stage is erected, just half the height of the whole Press; then one set of the bales are made up on the floor, and the other upon the stage. Suppose the follower raised up above the level of the stage, a bale of goods is placed on the lower bed, and by turning the winches, the follower is forced down upon it, till it is sufficiently pressed; now, while the men below are tying and making the bale fast, the people on the stage place a bale upon the follower; and it is plain that when the follower is raised up to relieve the lower package, the upper bale will be compressed between the follower and the head of the Press; and while this is making fast, the workmen below get another bale of goods loaded in. By this means no time is ever lost in screwing up or opening the Press; for it performs work both ways, which is a matter of no small importance in large works.

Press with
differential
screw.

(422.) In the *Philosophical Transactions* for 1781 is an account of a double screw, applied to a Press by Mr. W. Hunter. To explain this, we must suppose a single Screw Press of the ordinary form, but the lower end of the screw, which rests upon the follower or presser, has a second screw of finer thread cut upon it. This thread is received into a nut or barrel, which rests upon the presser. The nut is at liberty to turn round freely upon the presser, except when it is required to be stationary; and then by a key it can be fixed fast to it. In like manner, the nut or barrel can at pleasure be fixed fast to the lower screw by a key put through a hole in both; and in this state they will of course turn round together. As the nut and lower screw take up some room, the screw is turned by arms fixed in a head formed on the upper end of it above the Press. In the operation of this Press the nut or barrel is pinned fast to the lower screw by the key; and the screw being turned by the arms at top, the nut is carried round with it, and the effect is exactly the same as an ordinary Screw Press. But having by this means given as great a pressure as the single screw is capable of producing, the cross key which unites the lower screw to the barrel is removed, and is put in such a position, that it unites the barrel to the presser, so as to prevent its turning round upon it.

Machinery.

The effect of the Press now becomes compound, and while the whole screw is carried downwards by the revolution of the great screw, the fine screw at the bottom of it screws down into the barrel or nut, which is attached to the presser, which is therefore carried down a quantity only equal to the difference of the thread of the two screws; and if these are made very nearly alike, the descent produced by the difference between them will be exceedingly small, and the power exerted upon the articles under pressure will be in proportion to it. Indeed, the effect would be the same as if a single screw had been employed, having its threads so fine or close together, that the difference between thread and thread is only equal to the difference between the threads of the two screws.

For example, suppose it was required to produce a strong pressure, with a screw of ten threads in an inch, it is evident that the metallic protuberance, or helix of the screw, could not be quite so thick as one-twentieth of an inch, and could not, therefore, withstand any considerable force; but by the present construction, we may have the thread as strong as can be desired. Thus, if the slightest be a quarter of an inch, the finest screw must have two turns in the inch, and the coarsest two turns in one inch and one-tenth; or in other words, it would pass over the same space in ten turns that the other screw would in eleven.

These differential screws are extremely convenient in measuring small quantities, without requiring very fine screws. The finest screws usually to be met with do not exceed 100 threads in the inch, and few have been made finer than 200 in the same space. Let us consider by what threads of the usual or even coarse numbers we could have a difference per turn of 1000th of an inch, and we shall find that the difference between a thread of 32 and one of 33 in the inch is the 1056th part of an inch; so likewise the difference between a 60th and 61 parts of an inch is the 3660th part.

The writer has seen a delicate application of this principle by Mr. Barton, formerly of the Mint, who had two screws of 100 and 101 threads to the inch, which by their difference is equivalent to 10,100th part of an inch; but one being furnished with a micrometer head, which might be read to 100th, furnished the means of measuring a quantity of less than 1,000,000th of an inch.

(423.) *Hydraulic or Hydrostatic Press.*—The principle on which the Hydraulic Press is founded, which depends upon the equilibrium of pressure in fluids, was long known before the idea was suggested to apply it to mechanical purposes; and after the idea was advanced by Pascal, it was still more than a century before it was put in practice by Mr. Bramah, who took out a patent for the invention in 1791. Since this time the Hydraulic Press has gradually superseded the use of the Screw Press in most cases where great power is required; and, indeed, in all cases its application is more simple, its operation more expeditious, and the power almost unlimited, whether it be employed in the actual process of pressing, or in drawing or lifting great weights. Experiments have been made, in which piles, driven for the purpose of forming coffer dams, have been drawn by it with ease; even large trees have been drawn up with it by their roots, and iron bolts and cables, capable of holding the largest vessels in the British Navy, have been torn asunder with it in a few minutes. As it will be necessary to speak of the Machine in several of our descriptions, we shall in this place only explain its operation as a simple

Hydraulic
Packing
Press.

Manufac-
tures.

Pl. xxxiv.
Fig. 2, 3, 4, 5.

Press for packing, and describe the general principle of its action, and the mode of packing or leathering, leaving the more minute account of its operation to be particularized in the mechanical processes in which they occur.

(424.) A very simple form of packing Press of this kind, as it is constructed in several of our Government establishments, is shown in fig. 2, where F represents a short strong iron cylinder accurately bored and fitted with a solid plunger or piston rod D, both very accurately turned; this cylinder is sustained in the bottom cross bar of the Press, and sunk below the floor. A A are two strong iron sides, either cylindrical, or having any other figure at pleasure; a cross beam unites these uprights above by screws, and nuts or keys at *a a*, and an iron plate E is attached to the top of the piston rod, and guided in its motion by the uprights A A. L is the cistern of the forcing pump, and *b* a small pipe connecting the pump with the cylinder, which it enters as shown in the figure. And this constitutes the entire principle of the Press; for whatever pressure is exerted on the small area of the valve where the pipe enters the cylinder, that amount of pressure is multiplied in the Press as many times as the area of the plunger exceeds that of the valve. If, for example, the diameter of the valve were $\frac{1}{4}$ of an inch, and that of the plunger 6 inches, the area of the sections would be as $\frac{1}{16}$ to 36, or as 1 to 576; a pressure, therefore, of 10 pounds on the valve would produce a corresponding pressure on the press of 5760 pounds, or supposing the leverage of the pump to give a power of 10 to 1, then a pressure of 1 pound at H would balance a weight of 5760 pounds at E. Such is the simple principle of this powerful Machine; but where such great pressures are sustained, particular care and precautions are necessary to insure accuracy and to prevent leakage, which, as we shall not again touch upon the subject where we may have occasion to refer to this Machine, we propose to describe in this place; premising only that we have here only a single pump, whereas in the most powerful of these Machines there are three, four, or more pumps with double handles worked like a fire engine, and sometimes the cylinder of the Press is open at both ends, and the plunger or piston rod passes through both, the diameter at the upper end being much greater than at the lower, so that the area of pressure is the difference between the two sections. One advantage of such a construction is that the piston rod is thus guided in its direction without requiring aid in this respect from any external body; in this form also it is more convenient for bringing on a pulling instead of a pushing or pressing force. The pump does not differ essentially from another forcing pump; it is supplied with a valve below, commonly of the conical form to admit water from the cistern, when the plunger is raised, and another opening towards the pipe *b* to admit the water, when under the action of the plunger, into the pipe and cylinder; it is also supplied with a steel yard safety valve, and a screw cock for relieving the Press, and for returning the water into the cistern when the operation is completed, or at any other time. The safety valve is shown at *k*, and the relieving or the return cock at *i*.

Method of
leathering.

(425.) It now remains only to explain the means had recourse to for preventing leakage in the cylinder. For this purpose, the cylinder D is surrounded by a collar of leather at *o o*, fig. 3, the leather being formed as shown in fig. 4, the former figure representing the

upper end of the cylinder, and the latter the leather turned up to form a double cut, so that it resembles the cuff of a coat sleeve. When in its place it is kept distended by a copper ring, entering the circular channel or fold of the leather. This ring has a lodgement in a recess formed within the cylinder F. The leather is kept down by a brass or bell metal ring *m*, which is received into a recess formed round within the cylinder, as shown in fig. 3. The interior aperture of this ring is adapted to receive the cylinder D, and thus the leather becomes confined in a cell, with the edge of the interior fold applied to the cylinder D, whilst the edge of the outer fold is in contact with the interior surface of the cylinder F. In this situation the pressure of the water, acting between the folds of the leather, forces its edges into close contact with both, and makes a tight fitting round the cylinder, and as the pressure is increased, the leather is applied more closely, so as to prevent leakage under any circumstances. The metal ring *m* is truly turned in the lathe, and the cavity or cell formed for its reception; then to get it into its place, it is divided by a saw into five segments, as in fig. 5. Three of the lines at which it is divided point to the centre, but the other two are parallel to each other, and the ring is put into its place (after the leather and copper rings are introduced) by putting in the four segments separately, and the one with parallel sides is put in last. The cylinder D is then put down in its place, and ready for action. This plan of a divided ring was first used by the late Mr. Peter Kier, who, after the expiration of Mr. Bramah's patent, made several Hydrostatic Presses. In the original construction, the ring or head of the cylinder, which kept down the leather cup, was held down in its place by several screw bolts, but as these had to bear a greater force than the whole power of the Press, they were frequently torn out or strained, so as to cause leakage. The upper part of the cylinder above the ring *m* is filled with tow, or other kinds of packing, impregnated with sweet oil, which is confined by a thin plate or ring. This packing serves at once to supply the cylinder with oil, and to prevent the admission of any substance which might injure the surface of the piston.

(426.) The operation of this Press may be very readily comprehended, by supposing the pump, cylinder, and connecting pipe *b* to be filled with water, and that an adequate supply of water is contained in the cylinder L. When the handle of the lever H is raised, it brings up the piston rod *f*, which would leave a vacuum beneath, if the atmosphere did not force the water through the lower or suction valve of the pump. The lever being then pressed down, the piston rod, by descending, diminishes the capacity of the pump; this causes the lower valve to shut, and forces the water through the lower valve, whence it passes by the pipe *b* into the cavity of the great cylinder F, and raises the piston D and pressing table E, together with its load, a distance proportioned to the quantity of fluid injected. On the subsequent rise of the piston of the pump, the descent of the upper valve prevents the return of the water, and consequently the fall of the cylinder D. A repetition of the same process injects more water, and the pressure may, in this manner, be carried to a great extent. When it is proposed to relieve the action of the Press, the discharge valve *i* must be opened by turning the screw back; the water then escapes out of the Press into the cistern L, and consequently the table E and the

Machinery

Operation
of the
Press.

Manufactures.

Power gained by the Press.

cylinder D, descend by their weight, restoring the engine to its original situation.

We have already pointed out the proportional power of the Hydraulic Press, supposing one pump only, but it has also been observed that there are frequently several pumps and several men employed, when of course the power is much greater; and in these cases there is commonly a convenience of shutting off one pump and then another as the pressures increase, so that at length the power of six or more men is thrown upon one pump only, and a pressure is obtained of perhaps two hundred tons or more; and the Presses in many cases are ensured to that amount. These, however, are not packing Presses, but such as we have described under the article Proving Machines for Iron Cables, and for such purposes. Mr. Farey, in making a comparison between a Press of this description and the common Screw Press observes, that a man in the act of pumping by a downwards pressure, can without difficulty apply his whole weight, and with great ease one-third or one-fourth of his weight, which we may take at a medium at 50 pounds. Supposing, then, the leverage of the pump, together with the ratio of the valve to an inch surface on the piston, to be as 1 to 120, every inch of the piston will sustain a pressure of 6000 pounds, or nearly three tons; and in comparing this with a Screw Press, he observes, we must first inquire what fineness of thread and length of lever would afford a purchase of 120 to 1. Let us suppose the thread of a screw, substituted in the place of the cylinder D, to be one-tenth of an inch thick, the distance from the top of one thread to the top of the next will in this case be one-fifth of an inch. This is the space through which the weight must rise in one revolution of the screw; the power must, therefore, move through 120 times that space, namely, twenty-four inches. A lever or radius four inches long will describe a circle somewhat longer than this, and consequently such an engine would, in theory, be equal in power to the Hydraulic Press we have been describing.

But when the subject is viewed practically, the difference between the two Machines appears to be very remarkable. All practical men know how very large a part of the force, operating by means of engines, is employed in overcoming friction; every one is aware of the extreme friction between solids, and the very slight friction which takes place between the parts of fluids. This is seen in the common expedient of oiling the pivots of the wheels, and in the very gradual decay of motion in fluid bodies, while solids moving upon each other stop at once as soon as the force is diminished to a certain degree. The screw is a power peculiarly liable to friction, and this friction is always much greater than the whole of the reacting force; for there are few instances where a screw will return from extreme pressure, when the agency upon the lever is withdrawn. It is also to be considered, that the whole force of the weight or resistance acts directly upon the face of the thread of the screw at the place where the motion is required to take place. It has not been ascertained in what degree this resistance or friction increases with its weight. In lighter actions the simple ratio has been inferred, but under more severe pressure, the two metallic faces exclude the greater part of the semifluid matter between them, and appear by the magnitude of their resistance to be attached to each other by cohesive attraction.

Mr. Nicholson, in his *Journal*, relates the following experiments, which he made with one of Mr. Bramah's

VOL. VII.

small Presses, which he makes for the purpose of copying letters or writings, in the manner of Mr. Watt; it had the same parts which we have described, but the frame made of wood. When employed to press papers, the force applied to the lever of the injection pump was so slight, that the instrument required no fastening to the table on which it stood; but the effect of the upper bar, which was of wood three inches and a half thick, was such, as bended it out of a straight line upwards of a quarter of an inch, and it appeared that it might have easily been broken by continuing the pressure. With a Screw Press, the screw of which was iron, and nearly of the dimensions above mentioned, excepting that the lever was twelve inches long instead of four inches, and the action on the lever upwards of two hundred weight, applied with a jerk, the effect was nearly the same; he estimated the advantage to be very much in favour of the Hydraulic Press.

In another Press of this kind, the diameter of the greater piston was four inches, and of the smaller three-eighths of an inch, and the advantage given by the lever or handle was twelve to one. Above the piston of the great cylinder was applied a long lever, at one end of which was an axis, and at the other end a large scale to hold weights; it contained twenty hundred weight. The distance between the axis of motion of this lever and the part where it acted on the piston was six inches; and the distance from the same axis to the extremity where the scale was hung was one hundred and twenty-six inches, every hundred weight in the scale consequently pressed upon the piston with a force equal to twenty-one hundred weight, whence the whole pressure was twenty-one tons. It was easy to work the lever briskly with one hand, and each stroke raised the scale nearly one-third of an inch. Forty-seven pounds, hung at the end of the lever, carried it down with a moderate swiftness of working; but a weight of only forty-three pounds remained in equilibrio, and did not descend. Now as the true weight in theory was thirty-two pounds, as deduced from the dimensions of the parts in the manner already done with regard to the small Press, it follows that less than one-third of the actual power was employed to give velocity and overcome all friction.

It may be remarked, that the principal friction in these Presses must be at the circumference of the pistons, and that these do not increase in the simple, but in less than the subduplicate ratio of the power. For if the diameter of the great cylinder were doubled, and every thing else remained unchanged, the surface of its piston, and consequently the power, would be quadrupled, but the friction would be only doubled, and that merely at the leather ring of the greater piston.

As the pressure, in the experiment last mentioned, amounted to 47,040 pounds upon the great piston of four inches diameter, and sixteen circular inches surface, it amounted to 2940 upon each circular inch: now the medium pressure of the atmosphere on a circular inch is nearly twelve pounds, consequently the action was equal to 245 atmospheres, and as each of these corresponds with a column of thirty-four feet of fresh water at a medium, the water in the cylinder was pressed in the same manner as if the whole column had been 8330, or one mile and two-thirds perpendicular height.

Large Presses of this construction are, as has been stated, generally made with two or more pumps of one

2 11

Machinery.

Manufac-
tures.

Strength
necessary to
be given to
Hydraulic
Press cy-
linders.

inch and a quarter bore, and a cylinder of seven inches. These have been used in pressing hay and cotton for packages, and are very effective in producing a greater condensation on the material, with a much less application of moving power and consumption of time.

(427.) After what has been stated respecting the enormous pressures to which the cylinders of these Presses are exposed, it becomes an object of no small importance to estimate correctly the thickness of metal necessary to withstand such internal force. The following investigation on this subject is extracted from a Paper presented to the Society of Civil Engineers by Mr. Barlow. The internal strain on a cylinder was first determined by Mariotte, and Mr. Barlow by a different process arrives at the same conclusion; viz. that the circumferential strain on any given point of the interior of the cylinder is equal to a pressure on a square inch multiplied by the number of inches in the radius. That is, the force tending to rend the cylinder along any line parallel to its axis is equal to a pressure on a section between the circumference and axis. This, as we have said, is the result which has always been deduced by writers on this subject; but in estimating the thickness necessary to resist this strain, it has universally been supposed that all the metal in the thickness opposed an equal resisting power; from which it resulted that in Presses of the same internal diameter the thickness ought to be proportional to the pressure. This principle, however, is known to fail in practice, it having been always found requisite to increase the thickness in a higher ratio than the pressure; and it was principally with a view to correct this error, that the author undertook the investigation, at the earnest request of some of his practical friends; and having completed it, it was presented to the Society of Civil Engineers, who now rank amongst their numbers many of the most distinguished names of the united kingdoms connected with scientific and practical Mechanics.

The following is the particular part of the investigation to which we have alluded, viz. to ascertain the nature of the resistance opposed to any given thickness of metal in a cylinder or ring from internal pressure.

It would appear at first sight that having found the strain on any points, D and C, it would only be necessary to ascertain the thickness of metal to resist this strain, when applied directly to its transverse area. This, however, is by no means the case; for if we imagine, as we must do, that the iron, in consequence of the internal pressure, suffers a certain degree of extension, it will be found that the external circumference participates less in this extension than the interior; and as the resistance is proportional to the extension divided by the length, it follows that the interior circumference and every successive circular lamina from the interior to the exterior surface, offers a less and less resistance to the interior strain. The laws of which decrease of resistance it is at present our object to investigate.

In the first place, it is obvious that whatever extension the cylinder or ring may undergo, there will still be the same quantity of surface in the section of the ring, which area is always proportional to the difference of the squares of the two diameters.

Let D be the interior diameter before pressure, and $D + d$ its diameter when extended by the pressure. Let also D' be the exterior diameter before, and $D' + d'$ the same after the pressure.

Then from what is stated above, we shall have

$$D'^2 - D^2 = (D' + d')^2 - (D + d)^2,$$

or

$$2 D' d' + d'^2 = 2 D d - d^2,$$

whence

$$(2 D' + d') : (2 D - d) :: d : d';$$

or since d and d' are both very small, this becomes

$$D' : D :: d : d'.$$

That is, the extension of the exterior surface is to that of the interior as the interior diameter is to the exterior. But the resistance is as the extension divided by the length; therefore the resistance of the exterior surface is to that of the interior as

$$\frac{D}{D'} : \frac{D'}{D}, \text{ or as } D^2 : D'^2.$$

That is, the resistance offered by each successive lamina is inversely as the square of its diameter, or inversely as the square of its distance from the centre; by means of which law the actual resistance due to any thickness is readily ascertained.

Let r be the interior radius of any cylinder, p the pressure per square inch on the fluid, t the whole thickness of the metal, and x any variable distance from the interior surface. Let also s represent the strain exerted, or the resistance sustained, by the interior lamina, then by the law last deduced

$$(r + x)^2 : r^2 :: s : \frac{r^2 s}{(r + x)^2}$$

= the strain at the distance x from the interior surface; consequently

$$\int \frac{r^2 s dx}{(r + x)^2} + \text{cor}$$

= sum of all the strains; and this, when $x = t$, becomes

$$R = r^2 s \left(\frac{1}{r} - \frac{1}{r + t} \right) = \frac{s r t}{r + t}.$$

That is, the sum of all the variable strains or resistances on the whole thickness t , is equal to the resistance that would be due to the thickness $\frac{r t}{r + t}$ acting uniformly with a resistance s .

Let us now suppose (the above law being established) the radius r , and the pressure per square inch on the fluid p , to be given, to find the thickness necessary to resist it, or such that the strain and resistance may be in equilibrio, the cohesive power of the metal being also given. Let x represent the thickness required, c = the cohesive power of the metal per square inch, then

the greatest strain the thickness $\frac{r x}{r + x}$ can sustain is

$\frac{r x c}{r + x}$, and the strain it has to sustain is $p r$; whence when these are equal we shall have

$$r p = \frac{r x}{r + x} c, \text{ or } p r + p x = x c;$$

whence

$$x = \frac{p r}{c - p}.$$

Hence the following rule for finding the thickness of the metal. Multiply the pressure per square inch by the radius of the cylinder, and divide the product by the difference between the cohesive power of the metal per square inch, and the pressure per square inch and the quotient will be the thickness sought.

Machinery.

Manufac-
tures.

As an example, let it be required to determine the thickness of metal in two Presses, each 12 inches in diameter, in one of which the pressure is $1\frac{1}{2}$ ton per inch circular and in the other 3 tons, the cohesive power of cast iron being 18,000 pounds per square inch.

Here $1\frac{1}{2}$ ton per circular in. = 4278 pounds per sq. in.
3 ditto = 8556 ditto

whence by the rule

$$\frac{4278 \times 6}{18000 - 4278} = 1.87 \text{ inches thickness,}$$

and

$$\frac{8556 \times 6}{1800 - 8556} = 5.44 \text{ ditto;}$$

whereas on the usual principle of computation the latter thickness would be exactly double the former.

Press for
horn, tor-
toise-shell,
&c.
Pl. xxxii.
Fig. 6.

(428.) *Press for pressing horn.*—Horn, tortoise-shell, and other animal substances are capable of being so softened by the application of a moderate heat, that they can be moulded by pressure into any required shape, and the surface may be imprinted with any design in the sharpest and most delicate relief. Another valuable property is, that pieces may be made to adhere firmly together without any cement. The process of forming articles of these substances is extremely simple. The horn or tortoise-shell is boiled in water until it becomes softened, and is then put into moulds of iron or brass, made in two or more pieces, and with cavities between them to correspond with the article which is to be fabricated, and with all its intended ornaments engraved in the interior surface of the mould. This mould being made hot, the horn or shell is put between its two halves, and the mould being put in a small Screw Press, the halves are forced together to imprint the horn and press it into the cavity of the mould. But if the article has any considerable relief, this cannot be done at one heat, and therefore the Press, with the moulds in it, is put into a copper, and boiled still longer; it is then taken out, and by a lever applied to the screw it is screwed tighter, so as at length to obtain the impression desired. When a single piece of horn or tortoise-shell is not sufficiently large to fill the mould, two or more pieces are put together; they are cut to fit to each other with a proper degree of overlap, and being sufficiently softened by boiling in water, the surfaces are forcibly pressed together, and they will thus be united as firmly as if they were originally in one piece. The Screw Press employed for this business is very simple, being only an iron frame with a screw through the top of it; and, for the convenience of putting it in and out of the boiler and copper, a small tackle of pulleys is fixed just over the copper, and by the side of it is a block of stone, with a hole or cavity in it large enough to receive the Press, and hold it firmly upright, whilst a lever or wrench is applied to the screw to turn it round and produce the pressure, which being done, it is again returned into the boiler. To obviate the inconvenience of thus lifting the Press in and out of the boiler, Messrs. Poltzapffell and Deyerlin, of London, have made the Machine represented in plate xxxii. fig. 6, which is a section through its centre. A A is a box or case of cast iron; B a boiler or copper to contain the water; and c the grate for the fire, which is to be placed beneath it to heat the water; E is the flue or chimney, at which the smoke passes off; F F G is a Press, made very strong of cast iron, and capable of being drawn up out of the water and let down into it at pleasure, by means of racks a a at

each side, which are actuated by pinions d d; the axes o of these pinions extend across the Machine, and have each a wheel at the end; these wheels are moved at the same time by two arms or endless screws, cut upon an axis, which extends from one to the other, and is turned by the handle H: the Press is guided in this ascent or descent by grooves in the side of the boiler. When raised up out of the water, the moulds, with the horn or tortoise-shell between them, are put beneath the presser, and a severe pressure is produced by turning the wheel K. This wheel has an endless screw R upon its axis, which works the teeth of a large wheel L, fixed on the top of the screw P. The screw is received into an interior screw formed within the box or presser I, which is guided and prevented turning round by the cross bar e e, through which the presser is fitted; by this means, when the screw P is turned round by the wheel L and endless screw, the horn or tortoise-shell is pressed between the moulds; the Press is then lowered again into the water of the boiler, in order to be still further softened by the boiling; but when the Press is down in the boiler, the screw can be screwed tighter by turning the wheel K until the desired impression is obtained. By turning the handle N the Press is then raised up out of the boiler, and by turning back the wheel K the pressure is released, and the moulds can be removed. The fig. a, b, and c represent a pair of moulds proper for forming a cylindrical snuff-box; a is the internal mould of the box, into the bottom of which a piece of shell, softened by boiling, and cut round, is first placed, and round the inside a long slip is curled, the ends being made to lap over with a proper joint. The external mould b is then put into the cavity of the horn, and is forcibly pressed by the screw so as to give the horn the shape of c when it is withdrawn from the mould: a similar mould is used for making the lid of the box. Small boxes, and those which are slightly raised, can be made from one single piece without joining, also tooth-pick cases and similar articles.

The Chinese are famous for making lanterns of horn very thin and transparent. We are informed in the *Annales des Arts*, that they employ the same methods we do of effecting the joining by softening the horn in hot water, but that they use a long beam or lever for making the pressure. This method is for making up the leaves of horn from small pieces; but as the boiling would disfigure these leaves, they are united together to form the lanterns, by warming them at the fire, and pressing the edges of them together by hot pincers, made flat on the inside; by this means the joints are so perfect that they can scarcely be perceived. See *Repertory of Arts*, Second Series, vol. xxix. where a particular account of the Chinese manufacture may be seen translated from the *Annales des Arts*.

(429.) *Presses used by Bookbinders.*—Three different Presses are employed by bookbinders, but one of them is nothing more than the common upright Press already described; the others which belong exclusively to that trade, are the sewing and cutting Press; the former, however, is only a Press by name, as it is not employed in producing pressure.

Sewing Press.—This is the Machine employed in sewing the sheets together prior to their being put in covers. It consists of a bed of hard wood of such thickness as to prevent its warping, the width of the largest size books, and about two feet or two and a half feet in length; a groove is cut through it which extends nearly

Machinery.

Manufac-
tures.

its whole length, and about an inch within one of its edges, and the same or a little less in breadth. At the extremities of this are erected two wooden screws furnished with nuts, and on these nuts rests a cross piece having two holes at its ends for passing it over the screws; the middle part of this cross bar is turned round, leaving that part containing the two holes broad and flat; between this bar and the opening in the bed are fixed lines, which are tightened at pleasure by means of the wooden nuts, and being all brought to a uniform degree of tension, the several sheets of the work to be bound are successively sewed to these lines. It should be observed that the lines below are held and fixed to their places by means of small keys in or under the bed of the Press. In old binding, and occasionally in modern binding, these lines or cords lie projecting at the back of the book, but more commonly now the back of the sheets, after being properly arranged and secured in another Press, have small grooves cut across where the lines are to be fixed, which are thus countersunk, and the back of the book is left smooth and level.

Bookbind-
er's cutting
Press.

(430.) *Cutting Press*.—This is a Press used for cutting and squaring the edges and ends of the sheets, and is used as well by pasteboard makers as by binders and stationers. It consists of two heavy pieces of wood in form of cheeks, connected by two strong wooden screws, which being turned by an iron bar draw together or set asunder the cheeks, as much as is necessary for putting in the books or paper to be cut. The cheeks are laid horizontally, commonly over a box or chest for receiving the cuttings. On the side of the cheeks are two pieces of wood of the same length as and fixed parallel with the screws which serve to direct the cheeks, and to prevent their opening unequally. This, in fact, constitutes the press part of the Machine, but there is always accompanying it a plough for cutting the paper; this plough slides on a fillet on the upper side of the cheek, carrying a cutting knife, which may be advanced by means of a screw so as to cut successively through the whole thickness: it is also removable for the purpose of being sharpened.

The plough consists of several parts, *viz.* a wooden screw or worm, which catching within the nuts of the two feet which sustain it on the cheeks, brings the knife to the book or paper, which is fastened in the Press between two boards. This screw has two directors, which resemble those of the screws of the Press. To make the plough slide square and even on the cheeks, so that the knife may make an equal paring, that foot of the plough where the knife is not fixed slides on a fillet or in a kind of groove fastened along one of the cheeks. The knife itself is a piece of steel, five, six, or seven inches long, flat, thin, and sharp, terminating at one end in a point; at the other end it is square for the convenience of fastening the plough.

Improved
stationer's
Press.

(431.) An improved form for a stationer's cutting Press was in 1833 presented to the Society of Arts by Mr. M. Staunton, two elevations of which we have given in plate xxxiv. fig. 6, 7, is the Press having the front of the cutting tub or chest removed, in order to see the interior: *a* is an additional board, having two equally divided scales *b b* inlaid in the front part, the thickness of the Press being allowed for in the measures. This board receives the adjusting or movable shelf *c*, on which the paper is placed to be cut, the shelf moving up and down by two screws which are fixed in it, and pass through the perforations *d d*; these screws are fixed by nuts at the

back of the board, as shown in the end view, fig. 6. Machinery These two scales enable the workman to set the board strictly level at any required height within the range of the scales, by adjusting it to the corresponding measure on each. The board *a* slides perpendicularly into its place in the framework *e f*, fixed within the cutting tub or chest. There are three studs, *g g g*, one on the top of the centre of the board *a*, another on the framework *e*, and the third on the part *f*. On the under side of the left cheek of the Press are three corresponding sockets, which fit on the studs, and thereby fix the Press and board *a* correctly together: the Press lies on the usual ledges *h h* exactly at right angles with the board *a*, and therefore the paper when resting on the shelf *c* and screwed in the Press is always kept upright. See *Transactions of Society of Arts*, vol. xlix.

(432.) We might enumerate many other Presses used in different mechanical processes, which, however, except those of the most simple kind, are found described under the articles treating of the respective subjects. Of the simpler kind we may mention

The *joiner's Press*, used by them to keep close the panels, &c., of wainscot, doors, &c. This consists of two screws and two pieces of wood four or five inches square, and two or three feet long, whereof the holes at the two ends serve for nuts to the screws.

Founder's Press.—This is a strong square frame consisting of four pieces of wood firmly joined together with tenons, &c. It is of various sizes; two of them are required to each mould, at the two extremes of which they are placed, so that by driving wooden wedges between the mould and frame or sides of the Press, the two parts of the mould for the metal may be pressed close together.

Presses for making cider, and other processes of a similar kind, differ in no respect from the common Press for packing, except that here the descending board commonly enters into a box or vessels, with holes to allow the juice or liquid expressed to issue out into proper vessels placed to receive it.

For Printing Press, Copperplate Press, &c. see PRINTING.

Proving Machines.

(433.) *Machines for proving the strength of chain cables*.—Since the very general introduction of chain cables into the British Navy, it has been thought essential to the safety of the service that every cable before it is issued from the stores shall be submitted to a certain strain according to the dimensions of the bolt from which it is formed, a certain proof being fixed for every description of cable. As the strains thus ordered to be brought on the cable, and particularly those of the larger kind, are very considerable, Captain Brown, the original inventor of the chain cable, had a Machine constructed on his premises at Millbank, Poplar, for this purpose; in which about one-sixth of the length of the cable was laid in a long bed with one end fixed to the extremity of a system of heavy levers well balanced, and the other to a system of wheels and axles worked by manual strength. The chain was thus stretched between the two extreme points, and the amount of the strain was estimated by the weights introduced at the other end of the system of levers. Afterwards Mr. Brunton, who took out a patent for an improved form of the chain cable, had at his Manufactory in the City Road, a proving Machine erected of an entirely different description. Here was of

Proving
Machines
for iron
cables.

Manufac-
tures.

course a long bed as in the former Machine, but one end of the cable was attached to a fixed point, and the other to the piston rod of an Hydrostatic Press; and the amount of strain was estimated by a small valve placed in the side of the body of the Press, every pound on the valve answering to about sixteen thousand times that amount of strain. These were both objectionable, or at least at variance with each other, the multiple of power in the last and the inertia and friction of the levers in the former were very great, and the result differing very considerably, they could not be safely depended upon. It appears, indeed, from Barlow's *Essay on the Strength of Iron*, in some experiments which the author made on both these Machines, that with different parts of the same iron bolt there resulted a difference of several tons, the general averages of the strengths on Brown's Machine being to those on Brunton's as fifty to fifty-nine. The Admiralty, unwilling to trust to these uncertain measures of the strength of their cables, have lately erected at Woolwich a Machine intended wholly for this purpose, which combines both the former means of estimation, and in which the levers are so nicely balanced and hung on knife-edges as to turn with an ounce weight in the scale, even when acting with a strain of many tons. The estimation by the water pressure was intended to register the same; but the friction is so great upon the rod which acts on the balance, that it is impossible to distinguish a change for several additional tons of strain, and this friction of course increases as the strain increases; this register is, therefore, but little regarded, and, indeed, as the other acts with so much freedom, it is not necessary. In order to prove the truth of the lever register there is a means provided for trying the balance against actual weights to the amount of four tons.

Proving
Machine
by Bramah.

This Machine was erected by Messrs. Bramah of Pimlico, and is no doubt one of the most perfect of the kind which has been executed. It consists of two cast iron sides cast in lengths of 9.5 feet each, with proper flanches for abutting against each other, and for securing the whole to sleepers resting on a secure stone foundation. The whole length of the frame is 104.5 feet, equal to one-sixth the length of a cable for a first-rate, so that the cables are tested in that number of detached lengths which are afterwards united by link bolts. The Press is securely bolted to the frame at one end of the same, and the cylinder is open at both ends. The solid piston is $5\frac{1}{4}$ inches in diameter in front, and $10\frac{1}{2}$ inches behind, so that the surface of pressure is the difference of the two

$$= \left(\frac{21^2}{2} - \frac{21^2}{4} \right) \times .7854 = 65.5 \text{ inches.}$$

The system of

levers hung on knife-edges are attached to the other end of the frame, and the cable is attached by bolt links to this and to the end of the piston rod. The first lever being properly balanced, and the cable attached to a short arm rising above the axis, this draws the other arm downwards, and at a distance equal to twelve times the short arm is a descending pin and ball; this acts in a cup placed on the upper part of the arm of the second lever, and this again acts on a third. The first two levers are under the floor, and pass ultimately into an adjacent room, where a scale carrying weights is conveniently placed, and the whole combination is such that every pound in the scale is the measure of a ton strain; and, as we have stated, the whole acts with such precision that one pound more or less in the scale very sensibly affects the balance. At

the same place is situated the scale, acted upon by the water pressure from the charge pipe of the Press; and the valve in this pipe is of such dimensions that, together with the lever by which it acts, the power is again such that a pound should balance a ton; but, as above stated, the friction is here so great, that it requires several pounds to make a sensible change in the apparent balance, and for this reason this scale is seldom used. The forcing pumps are in another adjacent room, and are worked by handles after the manner of a fire engine. At first, six pistons are acting, and the operation proceeds quickly; but as the pressure and strains increase, the barrels are successively shut off, till at length the whole power of the men is employed on one pump only, and on this the action is continued till the proof strain is brought on the cable. A communication is then opened between the cistern and cylinder, and every thing is again restored to equilibrium.

The following experiments show the strain actually employed to break chains and chain cables of different dimensions, according to the report of Captain Brown on his lever Machine.

Experi-
ments on
the strength
of chains
and cables.

	Tons. Cwts.	
$1\frac{1}{2}$ inch. Old sable, $1\frac{1}{2}$ inch square bars, cut into pieces 2 feet long, piled and rolled into bolts of $1\frac{1}{2}$ inch	73	10
$1\frac{1}{2}$ inch. Old sable, ditto, ditto	80	0
$1\frac{1}{2}$ inch. Gurcoft new sable, ditto, ditto	71	0
$1\frac{1}{2}$ inch. Keiolsken, Archangel, inch square bars, cut into lengths of 2 feet, piled, and rolled into bolts	71	0
$1\frac{1}{2}$ inch. Old bolts, found promiscuously, piled and fagoted by hand hammers at my works .	71	10
$1\frac{1}{2}$ inch full. English bars, piled and rolled .	86	0
$1\frac{1}{2}$ inch bore. Ditto, ditto	80	0

Twelve further experiments, made 13th September, 1816.

	Tons. Cwts.	
$1\frac{1}{2}$ inch. Old Dutch bolts, fagoted by hand hammers at my works	71	0
$\frac{1}{2}$ inch. No. 1, $\frac{5}{8}$ square, (Welsh iron,) hammered into blooms, and rolled into bolts, at the King and Queen works	78	10
$1\frac{1}{2}$ inch. No. 2, $\frac{3}{4}$ inch square, (Welsh,) manufactured as above	73	5
$1\frac{1}{2}$ inch. No. 4, (Welsh iron,) fagoted by hand hammers at my works	88	10
$1\frac{1}{2}$ inch. No. 6, $\frac{5}{8}$ inch square ditto, rolled, but not hammered, at the King and Queen works	76	0
$1\frac{1}{2}$ inch. King and Queen scrap iron	80	5

The links of these chains were of an oval-like form, 6 inches in the clear.

The mean of these experiments gives 76 tons for the strength of a double bolt of $1\frac{1}{2}$ inch diameter in the cable form, which corresponds to about $21\frac{1}{2}$ tons per square inch section. Now by the same Machine the mean strength of malleable iron per square inch is 26 tons; therefore the strength of iron in the cable form is to that of the simple bolt in about the ratio of 43 to 50. But the links of these chains were without stays. Brunton's patent consisted of introducing a broad ended stay of cast iron between the sides of the link, giving them the shape of an oval, which was found to add very considerably to their strength, the strain required in this form to break them being nearly as great

Manufac-
tures.

as that for the iron in its simple bolt form, so that the stay may be said to increase the strength by about one-sixth part; at the same time, however, it must be considered that the weight is also increased, although in a less ratio.

Description
of chain
cable used
in the
British
Navy.

Rates of Ships.	Best bower hempen cables, 100 fathoms.		Number of threads in each.	Breaking strains by experiment.	Diameter and weight of the bolt of the iron cable substituted for the preceding.	Strain for the proof.	
	Sizes. Circumference.	Weight.					
	Inches.	Cwts. qrs. lbs.		Tons. cwts. qrs.			
First-rate large ..	25	114 2 7	3240	..	2½ inches. 218 cwt.	81 tons.	
middle ..	24	105 2 17	2988	..			
small ..	23	96 2 27	2736	114 0 0			
Second rate	23	96 2 27	2736		89 0 0	2 inches. 186 cwts. 2 qrs.	72 tons.
Third large	23	96 2 27	2736				
small	22	89 0 12	2520				
Fourth 60 guns .	21	80 0 22	2268	..	1½ inch. 170 cwts. 2 qrs.	63 tons.	
58 guns .	19	66 0 21	1872	..			
50 guns .	18½	62 1 14	1764	..			
Fifth 48 guns .	18	58 2 6	1656	63 0 0	1¾ inches. 145 cwts. 3 qrs.	55 tons.	
46 guns }	17½	56 0 1	1584	..			
42 guns }							
Sixth 28 guns .	14½	38 0 21	1080	40 0 0	1⅝ inch. 87 cwts. 2 qrs.	34 tons.	
Ship sloop	13½	33 0 10	936	..			
Brig, large	13½	33 0 10	936	..			1¼ inch. 74 cwts. 3 qrs.	28 tons.
Ditto, small	11	21 2 15	612	..			
					1⅞ inch. 61 cwts. 1 qr.	23 tons.	

From the above Table the immense advantage of iron cables will be distinctly seen, and particularly when we consider that a hempen cable, on a rocky bottom, is destroyed in a few months, while the other will sustain no perceptible injury under many years' wear.

The following are the results of a set of experiments on ropes of different thicknesses.

	Tons.	cwts.	qrs.
4-inch circumference	4	19	0
3½-inch ditto	3	12	1
3-inch ditto	2	10	1

Machines
for proving
ordnance,
éprouvette.

(434.) *Machines for proving Ordnance.*—One of the first steps in proving ordnance is to prove the strength of the gunpowder, by which the powder proof of the gun is made, and this is done by what is called an *éprouvette*. This consists of a small brass gun suspended by an iron strap and bar from two points towards the muzzle and breech; the two bars unite above, and are attached to an axle, which lies across a strong frame mounted on wheels, to transport it from place to place; a graduated arc is also fixed to the axis which vibrates with the gun, and is graduated from 0 to the full extent of the arc. An index and bar move on the axis, the friction on the axis being only sufficient to allow the bar to remain in any part where it is placed, the index sliding over the arc like the index of a common quadrant: there is also a small adjusting screw attached to the index bar, by which, after the gun is charged, the index may be adjusted accurately to zero.

Conceive, now, the gun charged with a given small charge of powder, and left to take up its natural swinging position; the bar is brought down to the position in which the screw reaches the upper part of the frame; and if the index is not exactly at zero, it is adjusted to it by means of the screw. The powder being now fired, the gun recoils with the quadrant or graduated arc, but the index

The following Table shows the different kinds of best Machinery. bower cables at present employed in the British Navy, with the corresponding iron cables, and the strain to which each is respectively submitted.

remains in its place, being prevented from recoiling by the stop or screw; but in the returning vibration the friction on the axis and that of the index on the arc is sufficient to retain it in its place, and therefore when the motion of the gun subsides, the quantity of recoil, which is the measure of the strength of the powder, is shown by the index on the arc. Dr. Hutton, who made numerous experiments on this Machine, has the following remarks upon the use of it. "It is not," he says, "confined to any one particular size, or even shape; it may be either a short cannon or a mortar, the latter probably the best, and these may be either small or large. The present instrument, with a small cannon, is to be considered only as a model of the cannon sort, to be used and charged with two or three ounces of powder, and with which a multitude of experiments have been made with perfect satisfaction; the results, even from this size, being remarkably regular. If it be desired to try large charges, then a larger mortar or gun may be employed in the same way; but the present small one is quite sufficiently accurate and regular. Though the experiments that have been tried with this *éprouvette*, have mostly been with two ounces of powder, as a convenient medium charge, yet it is equally accurate with either more or less than that quantity; and it is remarkable, that it shows the slightest variation that has been made, either in the strength or the quantity of the powder.

"The instrument is so expeditious, simple, and easy in practice, that any common soldier, or other person, can learn the use of it completely in five minutes, employing it with safety and expedition, and setting down a register of his trials. So that we have thus united in the same Machine the valuable qualities of accuracy, uniformity, ease, and expedition.

"The Machine can easily be made, too, by any artist, from the preceding description of its construction; or

Manufac-
tures.

it can be executed at home, and sent to distant places, namely, the small parts of it, and there fixed to any small mortar or swivel gun."

In the use of this instrument for the constant regular practice of proving gunpowder, a certain mark or number of the divisions on the arch line may be fixed on, as a standard for the strength of the powder, which mark or number of divisions may be ascertained by charging it with any powder of approved strength or quality. And when once that mark or number is known, the Machine will uniformly rise to the same place at every trial, either accurately or within a small fraction, with the same quantity and strength of powder. But should any other quality of powder be used, the Machine will show the difference in its strength with the utmost nicety whether above or below the proof.

Method of
using the
éprouvette.

To practice with the éprouvette.—Charge it with two ounces, or any greater or less quantity of powder put in loose, without using any bag or cartridge, and without any ball, in the following manner. Pour the powder carefully into the ladle; then, as the piece hangs at rest in the horizontal position, introduce the ladle with the powder carefully into it, to the very bottom of the bore; as the ladle lies in this state, let an assistant push the gun gently forward a little, to raise the muzzle higher than the breech, and while he supports it in this position, turn the ladle of powder half round, to let the powder drop all out in the bottom of the bore; after which draw out the ladle, and introduce the other or flat end of it, with which press the powder lightly all together in the bore, and then let the gun gently down again into the horizontal position.

After the gun has been thus charged with powder, and before firing it, the index must be set exactly to the beginning of the divisions on the arch. This is done by first setting it near the mark with the hand, and afterwards bringing it exactly to it, by means of a screw in the other end of the index, above the stand of the Machine. In this manner, with one hand press the upper or screw-end of the index down upon the bar of the stand, and at the same time with the other hand turn the screw backward or forward, and you will perceive the lower end of the index; by that means move slowly backward or forward, till it come exactly to the beginning of the divisions.

Before firing the powder, observe to have the socket of the index, which fits upon the horizontal axis of the Machine, always pressed to it with a moderate degree of friction; so that it may not sensibly obstruct the vibratory recoil of the gun, and yet that the index may keep any position you give it, without slipping from the arch or the axis, as the gun returns again from the first vibration.

After the piece has been charged with the powder, and the index set exactly to the beginning of the divisions on the arch, as before described, it is to be fired by means of a thread of quick-match in the following manner. Take about three or four inches of fine quick-match, and introduce one end into the vent till it touch the powder in the bore, leaving the remainder to hang loose on the outside; then set fire to this with the port-fire, plucking this quickly away lest it should be struck with the stem that suspends the gun, which would somewhat check the recoil. After the gun returns from the recoil, stop the vibrations gently, without touching the index, and look what division on the arch the index points to, or stands at, which number will

show the strength of the charge. For more satisfaction, the same charge must be repeated two or three times, and the medium of all the numbers taken for the strength of the charge.

It must not be understood, however, that this proof by éprouvette, which is always employed before a gun is submitted to the powder proof, is the only proof which powder undergoes, this kind of proof being, in fact, only to ascertain that the powder retains the original force it had at its first examination.

(435.) Proving gunpowder.—The first step in examining gunpowder is by rubbing it between the hands for a few seconds, to find whether it contains any irregular hard lumps. The second is by blasting about two drachms of it upon a copper plate, and comparing the effect with that of an approved sort of powder. In this proof it should not emit any sparks, nor leave any beads or foulness on the copper. This being satisfactorily passed, it is submitted to a proof of strength by mortar or by the gun éprouvette above described.

The mortar proof consists in projecting a 68-pounder iron shot from an 8-inch Gomer mortar, at 45 degrees' elevation, with a charge of four ounces. In this proof powder, new from the mills, must give a range of not less than 380 feet; and powder that has been issued and returned into store, or regenerated and restoved powder, a range of not less than 350 feet.

By the gun éprouvette, with a charge of two ounces with the first of the above powders, the index of the éprouvette must describe an arc of 21 degrees; and with the other descriptions, an arc of not less than 20 degrees 30 minutes.

The proof of fine-grained or small-arm powder is with a charge of two drachms from a carbine barrel, to perforate with a steel ball a certain number of half-inch elm boards, wetted and placed three-quarters of an inch asunder, the first being 39 feet 10 inches from the mouth of the barrel. The best powder generally propels the ball through 15 or 16, and the restoved powder through from 9 to 12 of these boards. This powder is likewise submitted to proof by the gun éprouvette with a charge of two ounces, and the arcs described should be with powder new from the mills, not less than 26 degrees; and with restoved and all other descriptions of powder, not less than 24 degrees.

The last trial of powder is by exposing about one pound of each sort, accurately weighed, to the atmosphere for seventeen or eighteen days; during which time if the materials be pure, it will not increase at all considerably in weight by attracting moisture from the air. In this exposure, one hundred pounds of good powder should not imbibe more than twelve ounces of moisture, or somewhat less than one per cent.

Powder Marks.

The different sorts of powder are distinguished by the following marks on the heads of the barrels.

- | | | |
|-------|-----------------|------------------|
| L. G. | Large grain. | } Marked in red. |
| F. G. | Fine grain. | |
| R. A. | For rifle arms. | } Marked in blue |
| L. G. | Large grain. | |
| F. G. | Fine grain. | |
| R. S. | Restoved. | |

(436.) Proving balls and shells.—When a quantity of balls and shells are delivered into store, they undergo an examination and gauging, and afterwards the shells are submitted to a proof by the water process, to see that

Machinery.

Proving
gunpowder.

Proving
balls and
shells.

Manufac-
tures.

they are free from holes, cracks, &c. As in the state in which the balls and shells are received, they are commonly covered with rust, sand, &c., they are first cleaned carefully on the outside, by scraping off the rust and picking out any pieces of dirt which may get into external holes on the surface and hide blemishes which are fatal to the reception of the ball when detected. This process is carried on by hand in the larger kind of shells, but in the balls and smaller shells a Machine is employed, which is very simple in its construction, and effective in its operation. It consists of two circular plates of cast iron about two feet in diameter, fixed on an axle about three feet apart, and from one circumference to the other there pass a number of bars of iron about an inch square, and at about an inch distance from each other, forming a sort of drum or cage resembling a squirrel's cage; a door turning on a hinge is formed in one of the cast iron ends, large enough to introduce an eighteen-pound ball. Fifteen such balls weighing two hundred and seventy pounds, or more of a smaller kind, are introduced into the door, which is then securely shut, and by means of a winch at each end of the axle four men are employed to turn the drum round pretty smartly, the balls during the time rolling and grinding against each other and the iron bars above mentioned, till in about ten or fifteen minutes they are found to be freed from all the superficial rust; the door is then opened and they are taken out to be examined with respect to any deep holes or splits on their surface, and any such being found the ball is rejected, as such defects are found to interfere greatly with good and efficient practice. It should have been observed that the iron drum is suspended in a strong iron frame, which frame is supported on a transverse axle below its middle, and is held up or secured in front by an iron pin, so that when the balls are cleaned the pin may be withdrawn and the drum and carriage tilted endways, whereby the balls are delivered into a spout and conducted away to a little distance to undergo their further examination. The whole frame and drum are also mounted on an iron carriage with four wheels, whereby it may be transferred to any place instead of bringing, as was formerly done, all the balls to the Machine which was fixed in its place. This process being gone through, and the surfaces examined for holes, &c. as above described, the low gauge is applied to every ball. This gauge is a ring of iron very accurately turned to a given diameter, which is a little less than the diameter of the ball ought to be; a handle is attached to the gauge, and a man holding the handle tries the gauge to the ball, and if the latter passes the gauge, it is too small and is rejected; if not, another gauge called the high gauge is tried. This consists of a cylinder very accurately bored to a diameter a very little exceeding that of the ball: this cylinder is about eighteen inches long, and every ball which, after the preceding trials, will pass through it, is admitted, but if it sticks in its passage it is rejected. The balls which thus pass through the second gauge are immediately painted over with a thin composition of Grant's black and red lead and placed on the pile for future service.

It has been already observed that the larger sort of shells are all examined by hand. This process is carried on by means of old swords having a handle fixed on at each end of a broken blade; with these they are scraped all over to loosen all the sand that may be remaining; and internally all sand and other matter is removed, and

a strong puff from a pair of bellows is blown into them Machinery. by which the dust is forced out at the fuse hole. They are then examined by means of instruments to ascertain that they are concentric, and an empty fuse is driven into the fuse holes. The shell is then suspended in a vessel of water in such a manner as to be just covered but without admitting any water at the fuse. In this situation the nozzle of a pair of bellows is inserted into the empty fuse, and a strong compression of the air is made within; if in this process no bubbles of air rise in the water the shell is concluded to be sound and serviceable. When shells are condemned as unserviceable, the reason for condemning them is expressed by one of the following marks, — F — which implies a faulty fuse hole, or N X non concentric; W X faulty by water proof.

(437.) *Proof of guns.*—After the pains which are thus bestowed upon proving the accuracy and soundness of the balls and shells, it will readily be imagined that great care is taken to ascertain that the guns themselves are free from all kinds of flaws and defects. Proving guns and powder.

The first important inquiry is to determine whether the bore is every where of its proper dimensions; this is done by a long and very accurate parallel ruler formed of two perfectly straight steel bars, exceeding in length any of the ordnance at present used in the British service. The two bars forming the parallel ruler are united together at different parts of their length by uniting plates as in the common parallel ruler, (which has however commonly but two,) and all these are acted upon by one long bar which turns by a handle at the end, so that they may be opened to any proper distance and remain perfectly parallel. When properly opened, the ruler is introduced into the bore, and in order to prove whether the sides of the bore are parallel to these rods and to each other, another instrument is introduced. This is a long rod having another attached to it at one-fourth of its length from the lower end, and which are opened from each other by means of a spring at the upper end; a smaller roller is fixed at one end, and as the instrument is passed down the bore in contact with the edge of the parallel bar, the roller is kept pressed by the spring above mentioned against the side of the bore, and any deviation from true parallelism is magnified in the ratio of the lengths of the arms, that is as four to one, which is shown by an index attached to the end of the instrument. When the bore is every where true, and when, of course, the side of the bore is every where equidistant from the parallel bar, the index remains stationary through the trial; but if there is any want of accuracy in the boring, the ends will be compressed or expanded as the rod is passed down, and if it exceeds a certain quantity the gun is rejected.

This examination being passed, another instrument is employed to search for any holes which may occur in the sides of the bore. This is a long round wooden rod, perforated from end to end through its length. At one end are fixed a number of steel rods with points or hooks at their ends, and formed so as to spring open, but which are compressed together by an iron ring which encompasses them; this ring being fixed to an iron wire which passes through the rod, so that a person by means of this rod and ring can open or close the searcher at pleasure, or rather he may close them by forcing the ring upwards, but they spring open of themselves when the ring is pulled down. In using this instrument the ring is forced up and the rods are com-

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tures.

pressed, it is then introduced into the gun, and when at the breech the ring is pulled down by means of the rod above referred to. When this is done, the points of the searchers are by the natural spring given to the rods pressed against the side of the bore, and a labourer now works the rod about in all directions, and if any holes are present some one of the points is pretty sure to find its way in. Such being the case, the situation is carefully measured and another instrument is used to measure its depth, and if it exceeds a certain quantity the gun is condemned.

The proof having been thus far satisfactory, it is next to be submitted to the powder proof. This consists of charging the guns with a larger quantity of powder than constitutes the full practice charge; that is, the full charge being about one-third the weight of the ball, the proof charge is taken generally about half the weight of the ball, and sometimes two balls are introduced. The guns being thus charged, are placed on sleepers on the ground in the face of a high mound, a match and train are laid from one to another, and every person being removed to a safe distance, the train is fired and the guns successively deposit their balls into the mound. All that have sustained this proof are now submitted to the final water proof, which consists in forcing water into them under very considerable pressure; and if in this no signs are exhibited of the water penetrating through the metal, the gun is considered fit for service, and marked and reported serviceable accordingly. But it sometimes happens that after the gun has gone through all the former trials, the water proof will discover flaws which had evaded detection by all the other methods, the water sometimes issuing in a stream, and in others the whole surface becomes covered with a sort of dew through the pores of the metal; in either of which cases the piece is condemned. In iron guns there is in no case to be allowed in the length of the bore a variation exceeding .3 of an inch; in the diameter of the bore only .033 of an inch is allowed from a 42-pounder to an 18-pounder, and .025 of an inch from a 12-pounder to a 4-pounder; and in the position of the bore .25 of an inch out of the axis from a 42-pounder to an 18-pounder, and .334 of an inch from a 12-pounder to a 4-pounder is allowed. They are fired twice with the regulated charge with one shot and two high junk wads, and examined with the searcher above described after each round. In this examination they must not have any hole or cavity in the bore of .2 of an inch in depth behind the first reinforce ring, or .25 of an inch before the ring.

In brass guns the diameter of the bore must not vary more than .025 of an inch from the true caliber, and in the other dimensions in no case more than .2 of an inch. The regulated charges for these guns are as follows:

12-pounder,	} double full practice charge.
9 ditto,	
6 ditto heavy,	
6 ditto light,	} three times the practice charge.
3 ditto,	

Any hole or cavity .15 of an inch deep upwards or sideways in the bore, or .1 of an inch in the bottom between the breech and the first reinforce ring, or .2 of an inch upwards or sideways, or .15 in the bottom of the bore before the first reinforce ring, is considered sufficient to condemn them.

In mortars and howitzers the exterior dimensions are in no respect to deviate more than .1 of an inch in the

10 and 8-inch howitzers, and .05 of an inch in the 24 and 12-pounder howitzers, and Royal and Coehorn mortars and howitzers. Their bores and chambers must not deviate from their true diameters or positions more than .25 of an inch.

The brass mortars and howitzers are fired twice with their chambers full of powder and an iron shell; the mortars on their beds, at an elevation of about 75 degrees; and the howitzers on their carriages, at an elevation of about 12 degrees. The iron mortars are proved with a charge equal to the full chamber, and an iron shot equal in diameter to the shell.

In carronades, the bores and chambers must not deviate more than .05 of an inch from their true dimensions and positions. They are proved with two rounds, with their chambers full of powder and one shot and wad. A hole of .2 of an inch in depth in the bore, or of .1 of an inch in the chamber, condemns the piece. All ordnance, after having undergone these proofs and the subsequent searchings, are subjected as above stated to the water proof. This is done by means of a forcing pump, having a pipe or hose fitted and secured to the mouth of the piece, and a plug to stop up the vent. After two or three efforts to force the water through any honeycombs or flaws which there may be in the bore, they are left to dry, and generally the next day examined by light reflected from a mirror. If the bore should contain any small holes or flaws which have not been discovered by the former proofs, they are very readily found by this, as the water will continue to weep or run from the holes after the solid parts of the bore are perfectly dry.

When ordnance is suspected to be of bad quality, it is often subjected to a more rigorous proof, such as firing twenty rounds rapidly with a charge of powder equal to the shot's weight and two shot; and in doubtful cases, where the purity of the metal is suspected, recourse has been had to chemical trials and analysis. A quantity of clean filings, taken from a part of the iron free from rust, are dissolved in diluted sulphuric acid and the quantity of gas discharged. The plumbago which remains after solution is also separated by filtration and carefully weighed. Now it is a well known fact that the purer the iron, the greater is the quantity of inflammable gas obtained, and the less is the proportion of plumbago which remains after the solution. From these parts, therefore, a tolerable judgment may be formed of the quality of the metal: when the plumbago exceeds four and a half per cent. the iron will always be found deficient in strength, and there has been no instance of a gun bursting where the plumbago did not exceed three per cent.; that is, where one hundred grains of the metal did not leave more than three grains of plumbago. The colour of the plumbago is also to be attended to; when it is brown or reddish it is an indication of hard metal, and when in quantities and mixed with foreign substances, there can be no doubt but that the iron is too soft.

When ordnance is condemned as unserviceable for any of the foregoing reasons, it is marked as follows: — D × for faulty in their dimensions, S × by searcher, and W × by water proof.

(438.) *Punching Machines.*—There are a great variety of Machines falling under this description, their general purpose being to punch out parts from a plate of rolled metal: in some cases the part punched out is the object in view, as in cutting the blanks for coin, buttons, &c.;

Manufac-
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in others the part of the plate remaining after the holes have been formed or cut away is the part to be preserved, as in forming the fronts to ornamental steel and brass fenders, &c. The processes of cutting blanks for coin and buttons will be described under the articles Coining and Button making, and we shall therefore in this place speak only of what is properly called punching, in which part of the plate remaining after the operation is to be preserved.

Punching
iron plates

(439.) *Punching iron plates.*—There are various cases in the present state of the Mechanical Arts where the old process of drilling holes was formerly employed, which is now superseded by punching, and with a rapidity which is truly astonishing. In making steam engine boilers, either of sheet iron or copper, the several plates must be securely rivetted together; and the number of holes requisite to effect this is very great, as is also the power which at one impression shall cut a clean hole through a sheet of iron of half an inch or more thick. Yet this is done with such rapidity, accuracy, and apparent ease, as never fail to be highly interesting to the stranger who visits our Manufactories in which such work is under operation. The holes in the several plates which are to be united must necessarily be formed at very equal distances to admit the passage of the bolt, and they must be very exactly of the same size that the same bolt may accurately fit both. This bolt or rivet, when the plates are placed together, is introduced red hot by a man inside, who holds the head of a heavy hammer against the inside head of the bolt, while the man outside by repeated blows on the red-hot bolt forms the head outside and thus secures the plates together.

Machines for punching may be worked by steam or horse power, or by a man; for notwithstanding it would be very difficult so to arrange a Machine as to enable a man by the application of his strength to punch a hole of half an inch diameter in a plate of iron half an inch thick, yet by allowing him to accumulate his power by means of a heavy fly wheel, the operation is performed after the fly is once in motion with apparent ease. The general character of these Machines is, that a long lever is suspended near to one end which carries the punch, the other end resting on an eccentric turned as above stated, and which, by pressing this long heavy end upwards, depresses the other with great force, and thereby forms the hole required. In the subsequent part of the revolution the weight of the long arm of the lever makes it descend with the low part of the eccentric; this raises the punch and allows the iron to be moved on its bed to receive the next pressure.

Pl. xxxv.
Fig. 1.

A Machine of rather a lighter description is represented in plate xxxv. fig. 1. It is fixed upon a strong metal framework or bed *a a*, and is worked by horse power; a band is passed round the drum *c*, fixed on the axis of the fly wheel *d*, which communicates the motion to the pinion *e*, taking into the toothed wheel *f*; these wheels work in plummer blocks, supported on the upright frame *g g*. On the axis of the wheel *f* is placed the crank and roller *h* of the lever *i*, the fulcrum of the lever being placed at *k*; the iron to be punched is placed under the punch *l l*, sliding through the triangular case *m*, fastened together by flanches supported by the projecting piece of metal *n*. The piece punched out drops into a cavity made in the stone bed *o*, and shown by dotted lines. In the revolution of the fly, the lever *i* being raised causes the steel cutters *p p* to approach each other, and the punch *l l*, sliding through the case *m*, is de-

pressed; thus performing very accurately the operation of cutting and punching at one time. The length of the iron to be cut is regulated by an upright gauge on the other side of the Machine, against which the iron is thrust from the side; *q* is a guide frame for the lever.

It would be endless to describe the different forms of punching Machines and the different objects for which they are employed. They are used not only for the cases above described, but for all sorts of open ornamental work: for punching cards for weaving damask, for punching small holes in copper, brass, and iron plates for various useful purposes in different Arts and Manufactures, &c. &c. A patent for a Machine of the latter description was taken out a few years back which is exceedingly ingenious, and has, we believe, been found valuable.

(440.) The apparatus to which this patent relates is represented as being joined to a common fly Press; but it is obvious that it may be also united to various other Presses. To the bottom of the screw of the Press a vertical sliding part is connected, secured so by lateral pieces as to move up and down with the screw perfectly, steadily, and evenly, without any shake or deviation. The lower surface of this sliding part is to be made exactly horizontal, flat, and level, and of course is to be of a sufficient size to properly bear up and act on the punch plate, which is to be attached to it by screws. This punch plate, which in the first instance is supposed to be prepared for making a single row of holes, has a number of holes drilled in it in one line, at such distances apart as are suitable to the nature of the work to be executed; which holes are enlarged or countersunk at top to receive the heads of the punches, and thereby draw them up out of the work when the slide is raised. The punches are made of steel wire, properly hardened and tempered, and have their heads enlarged to fit the countersunk cavities prepared for them in the plate, either by hammering the heads at the sides, or by *setting them up* by hammering their upper surfaces.

Corresponding to this row of punches a matrice is to be prepared, having holes drilled in it exactly to fit the lower ends of the punches, in order that these may cut through the materials, which they are to perforate quite cleanly, and without leaving any burs; and the punches themselves must be made very level at their lower surfaces for the same purpose. The matrice must be very evenly and firmly fixed exactly under the punch plate, on the bench that supports the Press, so that the punches may enter it without any deviation, and be withdrawn again without experiencing adhesion in any part.

The part of the apparatus for holding the metallic plate, on which the punches and matrice above described are to act, consists of a horizontal frame of cast iron, within which another frame is fitted so as to slide back and forwards horizontally very evenly and steadily, and secured from deviation by side pieces screwed to the fixed frame, so as to effect this purpose. This sliding frame is made to move backwards and forwards by a long horizontal screw placed beneath it, near the head of which a groove is cut to receive a collar, attached to the end of the fixed frame in which it turns; and which collar, by being divided into two equal portions, is capable of being fitted more exactly to the groove, so as to preclude all shaking of the parts; the avoiding of which is very necessary for the perfection of the work to be performed by the engine. The metallic plate, which

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Patent
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Manufactures.

is to be perforated, is fastened to the two extremities of the movable frame by two or more cramps or small vices, the screws of which enter the plates of the frame, one of which plates is movable in the direction of the motion of the frame, to which it is fastened by horizontal screws running in the same direction, which screws, after the metallic plate is fastened in as described, draw it out to the full extent so as to make it lie quite even and level during the action of the punches.

This horizontal plate holder is fixed on a level with the top of the matrice on the press bench, so as to draw the plate evenly over it; and the row of punches being of course placed at right angles to the direction of the long screw, by which the sliding frame is moved, the distance asunder between the rows of holes formed in the metallic plate by the punches, will depend on the degree to which this long horizontal screw is turned round. To regulate which more exactly, its head is furnished with a ratchet wheel, divided into a number of spaces or teeth corresponding to the portion of the revolution of the long screw required to produce the intervals between the rows of holes in the plate; and a spring click or catch, acting on its ratchet wheel, shows when the horizontal screw has been turned sufficiently for a fresh row of perforations.

This simple form of the ratchet wheel and catch will be sufficient for large work, in which the perforations are not very close together; but when fine work is to be executed, in which the spaces between the holes are very small, a pinion is fixed on the head of the screw, which turns round a toothed wheel that is so much larger as the rows of holes are to be closer together; and pins, projecting from the face of the large wheels that come in contact with the end of the lever or hinged stop, regulate the space which the screw is to be turned for the purpose required.

It is plain that the relative sizes of the pinion and wheel may be so varied that the number of projecting pins may be either increased or so diminished that even one will serve for the purpose; an instance of which latter proportions is represented in the drawings of the specification.

It may be readily conceived how several rows of punches may be fixed in one plate on the same principle as the single row already described, so as to cut out all the holes required in a square or oblong plate at one pull of the Press. Round plates might also be perforated by punches placed in parallel rows; but the patentee directs that, when intended for plates of this form, they should be arranged in radial lines drawn from the centre of the circle within which they are to be fixed. He also describes another method of proceeding with circular plates that will be particularly useful when they are of a large size, which consists in arranging the punches in the radii contained within a sector of the circle required, of which sectors six, eight, or any other determinate number would compose its area; then punching a hole in the centre of the plate, and passing it over a pin prepared for its reception, the work is performed by moving the plate round this centre as each sector is perforated by the bed of punches, which is regulated by a stop placed to determine the portion of the circle to be perforated at each impulse, as might be managed by the plate being fastened by studs on a flat ring placed concentrically with it, and having notches on its edge to receive a spring catch, corresponding in number to the multiple of the sector necessary for completing the circle.

The patentee enumerates various uses to which plates perforated by this apparatus may be applied; among which he mentions the making sieves of all sorts, strainers for coffee-pots, plates for malt kilns and coolanders.

(441.) The system of punching, as applied to ornamental work principally, has been largely practised in Birmingham, and other places in this Country, for a long period; and the Machinery for it has been brought to great perfection, as may be conceived by inspecting even the large plates cut out in pattern work for common fenders, and other articles of a similar nature.

The great difficulty in making an engine for the purposes mentioned by the preceding section lies in the nice and extremely accurate fitting of all the corresponding parts necessary for its perfect performance; and on this head very ample directions are given in the specification, as far as regards the shape and adjustment of the several parts of the apparatus; but nothing is said of the mechanical means to be used by the artist in producing this exact correspondence of parts; we much wish that this point had been in some degree noticed; for though general methods of performing such work by gauges, moulds, &c. are well known, we cannot but suppose that the ingenuity of the patentee must have led him to some particular management in this respect, the communication of which would be valuable.—See *Repository of Arts*, vol. xlix.

(442.) *Registering Machines and tell-tales.*—Registering Machines are of a similar kind to Counting Machines, having reference to quantity as the latter have to number. They are introduced in various operations to prevent too frequent a repetition, and to mark if these are too few in number; as for instance, in the Manufactory of Congreve rockets, where a weight descending from a certain height ought to strike the composition only a certain number of times; and to prevent the workman either exceeding or falling short of the proper number of blows, a register is worked in another room, whereby a less number of strokes would be detected, and a greater than a proper number is prevented. There are many contrivances of this kind, but as they are generally fitted to the particular objects under operation, they will be best described, when necessary, in the places where they occur. We shall therefore in this place simply describe such as are not likely to occur again in this Work.

(443.) *Registering thermometer.*—This is one of the most simple registering instruments that we have. It consists of two thermometer tubes placed horizontally, one filled with quicksilver the other with alcohol slightly stained; the former being for registering the greatest heat, and the other the greatest degree of cold. The former has a small piece of iron, a little less in diameter than the bore of the tube, plated above the mercurial column, that is, between the extremity of the mercury and the end of the glass tube. Therefore as the mercury expands with heat, it pushes this piece of iron before it, and when by a change of temperature the column of mercury contracts, this piece of iron is left behind, and thus shows the greatest extreme of heat to which the thermometer has been exposed during the day or during the time of any experiment.

In the other thermometer, instead of a piece of iron, a very small thin hollow piece of glass, about half an inch long, is immersed in the fluid, and being specifically lighter than the fluid, it will, when the column is placed

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vertically, be found at the upper extremity. Now let the thermometer be placed with its tube horizontally, then as the fluid contracts with a reduced temperature, the adhesion between the fluid and the floating gauge will carry the latter back with it, but when the fluid again expands it passes the gauge, leaving the latter behind it, which thus marks the greatest retreat of the alcohol, or greatest degree of cold to which the thermometer has been exposed during the night, or during the time of observation. The two tubes being placed on their frame, in the same direction with respect to their bulbs, to use the instrument it is only necessary to take it from its horizontal position, and to turn it so as to bring the column vertical; then the iron by its gravity will descend and fall on the top of the mercurial column, while the glass gauge, being specifically lighter, will ascend to the top of the fluid column. The instrument is then set and ready for another observation.

Steam
engine
indicator.

(444.) *Steam engine indicator.*—This is also a registering Machine, the object of which is to indicate and register the state of the steam and exhaustion in the cylinder in different parts of the stroke of the engine, which cannot be done by the condenser and steam gauge, these being in a state of constant oscillation, and therefore all that can be gathered from them is a sort of mean estimate; but by means of the indicator the exact amount of both is shown. It consists of a cylinder about an inch and three-quarters in diameter and eight inches long, exceedingly truly bored, with a solid piston accurately fitted to it so as to slide easy by means of oil. The stem of the piston is guided in the direction of the axis of the cylinder, so that it may not be liable to jam or cause friction in any part of its motion. The bottom of the cylinder has a cock and small pipe joined to it, and a flat pillar is screwed to the cylinder of the indicator, which carries a frame twelve inches by seven, with an upper and lower rail grooved to retain a sliding board. This board, when the instrument is fixed in its place, is attached to a part of the engine which draws it forward every stroke, and it returns again by the action of a weight at the next or down stroke, so that this board is constantly being drawn backwards and forwards with every double stroke of the engine. The pipe of the cylinder indicator is screwed into a hole in the engine cylinder, and may be made to communicate with it or not at pleasure by turning the cock above mentioned. When the communication is opened, the piston in the indicator would of course be forced to the top, if not checked by some arrangement; but in its ascent it acts against a spiral spring, which is of such strength as to indicate by its compression the pressure of the steam at any time. The length of the spring is generally about seven inches, and when at rest the piston ought to descend to within an inch of the bottom of the cylinder when loaded with fifteen pounds to the square inch; when, therefore, the bottom of the indicator is in open communication with the cylinder of the engine, the piston will rise or fall according as the latter cylinder is open to the steam or to the condenser, and the quantity of its rise and fall will be proportional to the strength of the steam when rising, and to the state of exhaustion when falling; the stem of the piston is thus in continual motion, ascending and descending a quantity each stroke proportional to the pressure. The upper part of the stem is furnished with a pencil, acted upon by a slight spiral spring, which keeps it constantly pressed up against the sliding board above mentioned; and thus while the board (furnished with a sheet of white

paper) is drawn backwards and forwards at each stroke of the engine a given and fixed quantity, the pencil will rise and fall a variable space, depending upon the circumstances above named, and thereby describe a figure which will indicate the effect of the engine. If, for instance, the formation of the vacuum could be complete and instantaneous, the pencil would describe a direct vertical line, and if, at the end of the stroke, the change were equally complete and instantaneous, it would ascend in the same way, and the figure described would be a perfect rectangle; but as this is not to be expected, the figure described will deviate from the perfect parallelogram, and the power of the engine will be proportionally less as this deviation is greater, and greater as this deviation is less.

(445.) *Tell-tale for watchmen.*—This may be considered as a registering Machine. There are different contrivances for this purpose, but one of the most simple is the following. A common clock is made having only the hour motion, and instead of the hour hand revolving the whole face revolves, which consists of a light circle of wood or metal of such thickness as to admit of holes being made round its circumference to a certain depth within at every quarter of an hour distance, viz. in all forty-eight holes are made round its rim; into these holes are inserted brass pins, which stand out from the circumference about half an inch like the teeth of a spur wheel; the clock being wound up, works like any other common clock, except that instead of the hour hand this dial or wheel itself revolves in the same time as the hour hand would do, viz. once in twelve hours. Consequently, one of these brass pins passes the uppermost point of the clock face every quarter of an hour. Just at this place is a small hammer head fixed on a lever, to the other end of which is a line and handle like a bell-pull, which is conducted outside the building, or at least to a place where the watchman has access to it. The hammer head is held up over the brass pins by a spring, so as to admit of the dial revolving freely; but when the watchman pulls the string he compresses the spring, and the hammer head drives or presses the pin into its hole in the rim of the wheel; but if by any neglect he does not pull the spring in time, the pin remains in its projecting position to bear testimony of his negligence. Thus every quarter of an hour, or every half hour, as may be thought necessary, the watchman pulls the string, and in the morning his employer has the means of judging of his diligence during the night.

It will of course be understood that it does not require his immediate attention every quarter of an hour precisely; the pin is nearly the whole quarter of an hour passing under the hammer head, and any time during this interval, if the string be pulled, the pin will be driven back; but if once permitted wholly to pass, it will remain to tell its tale in the morning against the sleepy watchman. In the morning, by a very simple contrivance, the pins are again rendered projecting, and the Machine is again ready for its next night duty.

(446.) *Thermo-alarum, or fire-alarum.*—This is an ingenious little Machine, we believe invented by the late Sir William Congreve, which is intended to give an alarm in case of fire, or when the temperature of the room or apartment in which it is placed exceeds a certain amount. The principle of the action consists in the expansion of a quantity of alcohol in a large kind of pulse glass, that is, a glass about an inch in diameter, six inches long, with a bulb of two inches diameter at each end, fixed to a frame suspended very nearly but a

Fire
alarum.

Tell-tale for
watchmen.

Machinery.

Manufactures.

little below the general centre of gravity; to the frame is also fixed a tube with quicksilver, which is horizontal when the frame and pulse glass is set for action. Conceive now the frame to be very slightly inclined on one side, then the alcohol will descend towards the lower bulb, and give a preponderance of weight to the lower side; the frame is prevented from descending more than a very little quantity by a stop; in this state, therefore, the instrument is set at a certain temperature. Suppose now a fire to happen, or the temperature to be raised a certain number of degrees, the alcohol will expand and rise in the pulse glass, carrying some weight over to the other side of the centre of suspension, till at length this will become the heavier side, and the frame will tilt over on its point of suspension, and the quicksilver in the glass tube going with it will give to the frame a certain impetus sufficient to relieve a catch, which holds a spring already wound up: by this means the spring is let free, and will run down, and in so doing it rings a small clock or alarum bell, which gives notice of what has occurred.

Considerable nicety is required in suspending the frame, so that the centre of gravity shall be just over the point of suspension when the instrument is set; it must then of course be necessarily displaced by the rising of the fluid column, and carried over to the rising side, till at length its weight on this side is sufficient to cause a preponderance of weight on that side to tilt over the frame, as already explained. In some instruments of this kind they may be set to give the alarum at any proposed degree of heat, and being made ornamental, were intended by the inventor to be placed in ball and assembly rooms, to give notice when the heat should be such as to call for ventilation.

Clock alarum.

(447.) The *time alarum* or *clock alarum* is a small appendage to a common clock, or an instrument by itself acting only as an alarum. In the latter case it is wound up and works like a clock, but may be set so that at any proposed time it shall relieve a catch, and thereby cause the bell to be sounded with sufficient noise to wake a person, or to give notice the time in question has arrived. The description of this, however, belongs rather to the article Clockwork.

Tide register, or tide gauge.

(448.) *Tide registering Machine*.—This may generally be described to consist of a frame carrying three barrels, on one of which is wound very smoothly a long roll of paper ruled parallel to its length, with about twenty-four lines at equal distances to represent feet; the paper passes from this first roller over another and the principal roller or cylinder about a foot in diameter; the paper embracing by the position of the two rollers about three-fourths of its circumference, it then passes between this cylinder and another in contact with it. The middle or larger cylinder carries on its axis a brass wheel with teeth on its circumference, and in these teeth the leaves of a pinion works, which receives its motion from a good day clock; by this means the three cylinders are put in motion, being all suspended very freely, so that the only power required to turn them is simply what is just necessary to overcome their own friction and to drag the paper slowly from the first roller over the larger cylinder by its contact with the third roller. In this way it is easy to conceive that the paper is gradually and very slowly passed over the centre barrel. The pinion revolves once every six hours, and on the same axle with the pinion, but at the other end of the main cylinder, is a cam wheel with six cams, one of which therefore passes

every hour; these cams, as they pass the higher part of their revolution, lift a lever which, as soon as each passes, falls, and being furnished with a pricker marks a place on the paper indicating the situation of the paper at every hour; the pricker then just rises again above the paper by a very light spring.

Machinery.

This is all the duty performed by the clock movements; the rest is effected by the tide as follows: first, a well is sunk near to the room in which the clock is, below low-water mark, and is opened to the river, except that the aperture which communicates with the river is defended by wire gauze, to prevent the mud, &c. from entering. In this is a float consisting of a hollow iron vessel; to this is attached a rope, which passes over a wheel on an axle near the top of the well, and then descends again to a counterweight. Thus, as the water rises with the tide in the well, the wheel and axle are made to revolve, and when the water recedes the vessel descends and reverses the motion. The motion of the wheel, by a long horizontal shaft passing under ground, conducts its motion to the clock house, and by a bevelled wheel at its extremity communicating with a similar wheel on a vertical shaft, produces a vertical motion; the upper part of this shaft carries a horizontal wheel which moves a horizontal rack, the continuation of which passes over the Machine above described, and this carries a tracer or pencil, which is thus pushed forward and drawn back by every rising and falling of the tide, and always a proportional quantity to such rising and falling. Hence the tracer moving backwards and forwards every tide, while by the clock motion the paper is uniformly passing on, there is left on the paper an exact chart or representation of the state of the tide during which the Machine has been in action, which may be three or four days, or a week, according to the length of paper first supplied. When the paper is removed, parallel lines may be drawn through the hour dots, when the exact hourly rise and fall of the tide will be exhibited both graphically and numerically to the eye; the lines parallel to the length of the paper indicating the number of feet, and the lines parallel to the breadth the state of the same at every hour.

The above description will perhaps be rendered more intelligible by the author's own statement. "A number of parallel and equidistant lines representing feet in height are engraved and printed on dry paper, whose sides are carefully cut parallel, and the ends joined, until such a length is formed as to serve for three or four weeks' consumption. The long sheet thus produced is wound upon a brass roller, which is placed near the lower part of the cylinder, one foot in diameter, so as the paper may pass round that cylinder and be in contact with it through about three-fourths of its circumference. The contact with the paper is preserved by a roller pressing upon it by its own weight near the upper part of the cylinder. On the axis of the cylinder is a toothed wheel, which is to be acted upon by a clock, and hence follows the motion of the paper in the direction of its length, moving over equal distances in equal times: by means of the same toothed wheel motion is given to a cam wheel having six teeth, and the velocity is so regulated that it makes one revolution in six hours. Each tooth in the cam wheel raises in its turn a hammer, whose fall strikes an impression on the paper once in every hour; so that the spaces passed through are measured as they occur, and leave no error that might otherwise arise from the contraction or expansion of the

Manufac-
tures.

materials. It is obvious when the paper has been taken off the Machine vertical lines must be ruled across the paper through the hourly points made by the hammer, and any of them may be subdivided into less measures of time if required.

"Immediately over the axis of the cylinder, and parallel with it, is a rack which carries the pencil, and is acted upon by a pinion which receives its motion from a float resting upon the water; so that as the tide rises and falls the pencil moves backwards and forwards at a proportional rate through diminished space, and thus by the combined motions of the clock and the tide a line is produced on the paper which represents both. The impression hourly struck by the hammer is the figure of an arrow crossed in the centre, the point of intersection being that through which the hour lines are to be drawn. The marking point for the tidal line is of steel, which makes such an impression on the paper as may be easily traced with a camel's hair pencil when the paper is removed. A pencil usually called the metallic pencil may be employed for the original line if preferred. The float which rests on the water is a hollow plate iron vessel suspended by a chain, which passes twice round a light cast iron barrel, and then descends, having a counterweight attached to it. The chain is of such a length that both ends of it are always resting on the ground, so that the weight of chain on each side of the barrel is always equal. The float is placed in a well communicating with the river, and to prevent that undulating motion which would be produced by the motion of the surface of the river during high winds the water is received into the well through a fine wire gauze. The motion is communicated from the float in the well to the Machine in the house by a light horizontal shaft revolving under the surface of the ground, and communicating by bevelled wheels with an upright shaft which acts immediately upon the pencil rack." *Philosophical Transactions*, part i. 1831.

Shears for
cutting
iron, &c.

(449.) *Shears for cutting iron and other metals.*—The cutting of iron bars into separate lengths, or the cutting and squaring copper plate, &c., is performed by a powerful pair of shears on the same principle as the punching iron and metals generally, except that commonly the motion of the cutting branch of the shears is brought on rather more gradually than in the latter operation, the eccentric being commonly a circle.

Pl. xxxv.
Fig. 2.

In fig. 2, pl. xxxv. a pair of shears for this purpose is shown. A long and strong lever, A B, has a wheel moving on its axle, supported at its extremity; this wheel has a groove on its edge like a common pulley, and the large wheel has its edge formed to the same curve as this groove. This large wheel turns on an axle situated out of its geometrical centre by the aid of steam, horse, or other power; consequently, as the rotary motion is given to this wheel, the movable branch of the shears opens and shuts; the weight of the lever always keeping the small wheel in contact with the eccentric, and in its downwards action the power is so great as to part a bar or bolt of iron of considerable dimensions with the greatest apparent ease; and, indeed, the shock upon the person holding the bar is very inconsiderable, provided he applies it as near as possible to the axle of the shears; but if applied nearer to the point the jerk is very strong, and is likely not only to wrench the bar out of his grasp, but to do injury to the Machine. Shears for cutting copper, iron, and other plates act upon the same principle, the difference being only in the

dimensions and length of the shears and other parts of the Machinery.

(450.) *Machine for silvering looking-glasses.*—The invention of looking-glasses seems to be involved in some obscurity, and it is not the less so as we find the term looking-glass referred to in the translation of the Bible, at a period when it is questionable whether the material glass itself was known. In *Exodus xxxviii. 8.* we find, "And he made lavers of brass, and the foot of it of brass, of the looking-glasses of the women assembling, which assembled at the door of the tabernacle of the congregation;" but we can scarcely conceive that these were actually glass mirrors, but polished surfaces of metal; and indeed we can find no clue to the invention of the art of silvering glasses as practised at the present day.

Machine
for silver-
ing looking-
glasses.

It does not belong to this section to describe the previous steps necessary for silvering, as grinding, polishing, &c., these will be treated of in glass making, and glass grinding; our present business is simply to explain the process of silvering, particularly by means of the Machine described below, which was presented by Mr. Farrow to the Society of Arts, and for which he was rewarded by their large silver medal. See *Trans. Society of Arts*, vol. xlix. According to the former practice, a thin blotting paper was spread on a table or slab of marble, and sprinkled with fine powdered chalk, and this done, over the paper was laid a thin lamina of tinfoil on which mercury was poured and equally distributed over the foil with a hare's foot or cotton. Over the leaf of tin was laid a very thin and smooth kind of paper, and over that the glass plate, then with the left hand the glass plate was pressed down, and with the right the paper was drawn gently away. The plate was then covered with weights and the superfluous mercury driven out; heavier weights were then added, and the plate remained till it became dry, when the glass was complete. But in the more modern practice the common silvering table is a slab of stone ground to the most perfect degree of evenness, and placed in a frame so that a certain degree of obliquity can be given to it. All round the margin is a gutter, through which, at one corner, a hole is made, so as to allow the escape of the mercury when the plug that closes the hole is removed. It is this corner which is lowest when the oblique position is given to the table, in order that the mercury may be run to it from the other parts of the gutter. On the silvering table is spread a sheet of tinfoil of the same size as the glass, or rather a little larger; a fluid amalgam of tin is then poured on it, and spread over its surface with a brush till it adheres; more mercury is then poured on, till it stands about a quarter of an inch deep over the tinfoil. The plate of glass being previously made quite clean, is then slid gently and steadily from a sheet of paper, just dipping below the surface of the mercury, but avoiding to touch the tinfoil for fear of tearing it. When the glass is fairly over the tinfoil, the table is placed a little oblique by means of a rack, the mercury now runs into the gutter, and the glass subsides on the tinfoil. The whole surface of the glass is then covered with leaden seven pound weights, having cloth at the bottom; by this pressure, at the end of twenty-four hours, the silvering is so firmly adherent to the glass, that the weights may be removed, and the glass raised up in a sloping position, to allow the mercury to drip off till the silvering has become quite hard.

Mr. Farrow's improvement consists in dispensing

Manufactures.

Mr Farrow's silvering Machine.

Pl. xxxv.
Fig. 3, 4, 5.

with the loose leaden weights, and in producing the required pressure by means of screws. It is attended with the following advantages. First, all hazard of breaking the glass during the application of the pressure is avoided; when loose weights are used, one will sometimes slip out of the hand of the workman, and falling on the glass will break it. Secondly, the plate, as soon as the pressure is made by means of the screws, can be tilted up even in a vertical position, so as to expedite considerably the drip of the mercury from the silvering; an operation which is manifestly impossible where loose weights are employed. Mr. Farrow himself has hitherto applied this invention only to small plates for dressing-table glasses; but Mr. Wheeler, a manufacturer of looking-glasses, has applied the apparatus, with some modifications, to plates 47 inches long and 29 inches wide.

In plate xxxv. fig. 3 is a section of the Machine; *a b* the stone slab; *c d* its frame, containing the usual channel for the mercury; *e* one of the end supports, on which the bed can turn, for the purpose of being tilted; the middle strengthening bar *f*, which serves for an axis, is placed a very little on one side, to make the side *d*, at which the slope is given, always preponderate, that side usually resting on one or more screws, by which it is lowered or raised again. The dotted lines in fig. 3 show that side of the bed as lowest and resting on a small block. The upper and under sides of the frame *c d* are made quite parallel, to fit the hooked ends of the long clamps *g g*, which slide from one end to the other. The clamps are furnished with little plates *h h*; these project inwards for the clamps to stand and slide on when the screws are loosened. They are also, with the under hooks, made sufficiently wide, as shown in the end view, fig. 4, to prevent the clamps from falling on one side. A sufficient number of these clamps are provided to range over the bed about one foot apart; and the screw holes in one clamp are made to be opposite the intervals in the next, in order to distribute the pressure more equally over the surface of the glass; *i i i* clamping blocks of wood faced with leather; they hang on the screws loosely, so as to rise and fall with them and allow of being placed in any position. They are about seven inches long, and the screws are eight inches apart. The clamps are usually all drawn to one end of the bed, to be out of the way, and to make room for the glass plates being slid on, and need only be taken off when the largest glass is to be silvered, and then replaced to give the pressure.

Fig. 5 is an end view, or elevation, of a portable bed for silvering small glasses, and is Mr. Farrow's original invention; it has wooden sides *k k* rising above the bed, in which the several wooden clamping bars *g* slide. Here two screws only are used to each bar; and the battens that hang on their lower ends are in one piece. This, with the glass on it, is placed by hand in any required position. The glasses being quite clean for silvering, the faces of the battens or clamping blocks *i i i* never take any dirt whilst in use; and as they always remain pendent, with their faces downwards, when out of use, they keep clean, so that the glasses are not liable to any scratches from them.

Silvering glass globe.

(451.) In the *Philosophical Transactions*, No. 245, a method of *foliating* globe looking-glasses is given, communicated by Sir R. Southwell. The mixture is quicksilver and bismuth, of each three ounces, and tin and lead, of each half an ounce; to the last throw in the marcasite, and afterwards the quicksilver; stir them well

together over the fire; but they must be taken off, and be towards cooling before the quicksilver be put to them. When the mixture is used, the glass should be well heated, and very dry; but it will do also when it is cold, though best when the glass is heated.

Mr. Boyle's method, which he prefers to any which he ever met with in print, is this: take tin and lead, of each one part, melt them together, and immediately add of good tin glass, or bismuth, two parts; carefully skim off the dross; then take the crucible from the fire, and before the mixture grows cold, add to it ten parts of clear quicksilver, and having stirred them well together, keep the fluid in a new clean glass. When every thing is prepared to use, first purge it by straining it through linen, and gently pour some ounces into the glass to be foliated through a narrow paper funnel, reaching almost to the glass, to prevent the liquor from flying to the sides. After this, by dexterously inclining the glass every way, endeavour to fasten it to the internal surface; which done, let it rest for some hours; then repeat the same operation, and so continue at times, till the liquor is slowly passed over, and equally fixed to the whole superficies; which may be discerned by exposing the glass to the eye between that and the light.

(452.) *Sowing and threshing Machines* are used in agriculture for the purposes indicated by their respective names. Of these the sowing Machine is much more ancient than the latter, which is the invention of only the last century; whereas it appears from Beckmann's *History of Inventions*, that sowing Machines were known so early as the XVIth or beginning of the XVIIth Century, but the invention, he says, is not of English origin. Locatelli, a German, of whom, however, very little is known, is commonly considered as the inventor; and it is stated that experiments were made with a Machine of this kind by order of the Emperor of Germany, before a Commissioner appointed for the purpose, and were so successful that the inventor was rewarded by the Emperor, and sent with a letter of recommendation from him to the King of Spain. The small Tract in which this statement is recorded has no date except a written one on the title-page, which, if correct, brings the invention back to the last year of the XVIth Century, in the reign of Rodolphus II., who was much attached to mechanical inventions and pursuits.

In 1669, Evelyn gave to the Royal Society of London a complete description of Locatelli's invention; where it is also stated that, in consequence of the success attending the experiment in Germany, the inventor went to Spain, and proved by public experiment the advantages of the Machine. Locatelli published a small Work in Spanish, descriptive of the engine and its advantages. This was dedicated to Geronimo de Camargo, who was ordered by the King to make known and promote the application and sale of the Machine, the right of which was secured to the inventor by patent at a fixed price; and it appears that in 1664 great numbers of them were sold in Madrid.

The construction was exceedingly simple. The seed box, the cylinder of which was supplied with two small wheels, required only to be hooked or fastened, by means of ropes, to the end of the plough; it is, however, very inferior to the drilling Machine or drill plough of the present day; we do not therefore stop to describe it, particularly as the subject itself seems rather to belong to Agriculture than to Mechanics.

(453.) *Threshing Machines*.—These are a class of Ma-

Machinery.

Sowing and threshing Machines.

Manufac-
tures.
Threshing
Machines.

chines, the policy of introducing which as a substitute for the operation of the flail has been much questioned, and has given rise to various arguments, and to some disturbances in our agricultural districts. On general principles there can be no doubt that the farmer has equal right with the manufacturer to introduce any description of Machine which will enable him to produce his grain and bring it to market at the lowest price, as a benefit is thus ensured not only to the Agriculturist but to the Public generally. The question is therefore, whether it does cost the farmer less to use the threshing Machine or the flail. The former would undoubtedly be the cheaper if at the same time the labourer could be employed; but in too many instances where horses are employed in driving the threshing Machine, the labourer is idle and fed as a pauper at the expense of the parish; and in this point of view, the policy of employing mechanical means as a substitute for manual labour is certainly of a very questionable character. Still, however, it has been an object for many years past to introduce Machines for the purpose of threshing corn, some of which have been driven by wind, others by water, but more commonly by horses. According to Dr. Gregory, in the second volume of his *Mechanics*, the first threshing Machine dates its origin in 1732, having been constructed by a millwright in Edinburgh of the name of Menzies. It consisted, as far as can now be ascertained, of several parts resembling flails, which were attached to a movable beam, and inclined to it at an angle of about ten degrees. On each side of the beam were placed floors or benches, on which the sheaves were spread, and by the action of a crank attached to the beam, the flails received their motion, making each about thirty strokes per minute, whereby the corn was detached from the straw in a manner very much resembling the operation of a common flail in the hands of a farmer's labourer.

The next Machine of this description on record is also of Scottish origin, the invention of a Mr. Stirling of Dumblane; this was not completed till 1758. It was driven by a water wheel, having an inner wheel furnished with forty-eight cogs; turning on the same axle with this cog wheel was connected a vertical pinion or trundle with seven staves and the axle of which passed through a floor above the wheel, its upper pivot having been secured in a beam six inches above the floor. At the height of three feet three inches from the latter, two straight pieces of squared wood (each four feet in length) were inserted through the axle of the pinion, at right angles, so as to form four arms which moved horizontally. To the end of these arms were fixed four iron plates, each twenty inches in length, and eight inches in breadth at the extremity nearest to the arms, but tapering to a point at the opposite ends.

The horizontal fly here described constituted four threshers, which were inclosed in a cylindrical wooden box three and a half feet high, and eight feet in diameter; on the top of this box was an opening eight inches in width, extending a foot and a half from the circumference towards the centre, through which the sheaves of corn descended; the latter having been previously opened, and laid separately on a board provided with two ledges, gradually declining towards the opening; within the cylindrical box there was an inclined plane, along which the straw and grain fell into a wire screen or riddle two feet square, which was placed immediately beneath a hole of a similar size; the screw was jerked

at each revolution of the spindle, by means of a knob fixed on its side, and was thrust backwards by a small spring which pressed it in a contrary direction. Thus the short straw, together with the grain and chaff which passed through the wide screen, fell into an oblong straight riddle, one end of which was raised and the other depressed by a similar contrivance; and as that last mentioned was not provided with a ledge at the lower end, the long chaff which could not pass through dropped thence to the ground, while the grain and smaller chaff descended into a pair of common barn fanners, and were thus separated with great exactness. These fanners were moved by means of a rope which ran in a shallow groove cut on the circumference of the cog wheel. In the mean time, the straw collected in the lower part of the box over the wide riddle was drawn down to the ground through an opening two feet and a half square with a rake, by persons employed to form it into trusses.

Some other Machines for the same purpose were also projected and executed about the same time, one of which is described by the author above quoted, but the first completely useful threshing Machine was not constructed till 1785. This was the invention of Mr A. Meikle, whose ingenuity has been already recorded in the article Wind-mill. This Machine might be driven by wind, water, or horses, by the usual means already described under our article Mills. Supposing, therefore, the first rotation obtained, the essential part of the threshing Machine may be described as follows. On a sloping or inclined board or plane at one extremity of the Machine, the sheaves of corn (being first opened) are spread by an attendant; at the bottom of the plane are two fluted cast iron rollers of about three and a half inches diameter, which are made to revolve about thirty or forty times in a minute in opposite directions, which of course carry the corn and straw between them into a close casing within which is a horizontal hollow drum of about three and a half feet diameter also in rapid rotation. On the circumference of this drum and parallel to its axis, are fixed four leaves of wood each armed on one side by a thin projecting streak of iron. These leaves pass within about an inch, or less, of the iron rollers above named, and as the corn and straw pass through them, these by their action separate the corn from the straw, throwing it through an opening on its further side with considerable force, but it is prevented from flying away by another wooden casing above; it therefore falls down below upon a concave wire bottom or screen, through which the corn and small chaff fall into a hopper of which this screen forms the concave top. In the cylindrical space above the wire screen last mentioned, two cross arms revolve, carrying at their extremities rakes with teeth four or five inches in length. These collect together the straw and long chaff from which the corn has been extracted, and cast it out at an opening still further removed from the front of the Machine. The fanners above mentioned, by their operation at the lower part of the hopper, drive away the light and short chaff, and the corn which remains in the space below is generally considered fit for market.

The preceding description will be better understood by Pl. xxxiii. references to plate xxxiii., where N, fig. 5 and 6, represent the main axle of the Machine, which may of course receive its rotation from any first mover. On this axle in the particular Machine in question, is fixed the wheel DD, which carries 84 teeth and drives the pinion b of 24 teeth placed upon the axle b k. Upon the same axle

Machinery

Manufactures.

the wheel E E revolves carrying 66 teeth, which drive the pinion c of 15 teeth, and consequently the threshing-drum x x, which is fixed upon the same axle. The feeding rollers r r are driven by the intervention of the three toothed wheels h, e, d, the latter of which is fastened on the axis of the upper feeding roller. The wheel h upon the gudgeon h b contains 24 teeth, to act on the intermediate wheel that drives d containing 22; but when the fluted rollers require a greater velocity, e is taken from its iron axle, and a greater or less wheel substituted in its room. The short axle l m is furnished with a pulley p, which by means of the leathern belt or rope p p gives motion to the fanners placed below the threshing screen and straw shaker K K.

Fig. 6 represents a plan of the wheels, threshing drum, and straw-shaker, where the corresponding parts in fig. 5 are marked with similar letters. The wheels D D and h convey motion to the straw shaker, the largest one, D D, is fixed on the axis N, and carries 84 teeth, and drives the other which contains 14 teeth, which is placed upon the axis of the straw-shaker K K.

In this figure the straw and corn which are not seen in fig. 5 are represented on the feeding board at S where it meets with the fluted rollers r r, by which it is drawn into the closed case above referred to, and is exposed to the action of the four leaves w w of the threshing drum; here a great deal of the corn is separated from the straw and falls down below, while the straw and chaff containing still some corn, is thrown forward through a hole into another close case and is then subject to the operation of the straw-shaker K K.

Various threshing Machines are constructed, and a still greater number have been proposed which never were constructed. The reader who is curious to see some of the former may consult Gray's *Complete Millwright*; *The Repertory of Arts*, vol. lviii. and lix.; Gregory's *Mechanics*; Ferguson's *Mechanics* by Brewster.

Quantity of corn threshed.

(454.) The quantity of corn which a Machine will thresh in a given time, depends so much upon the judicious formation and position of its parts, that one Machine will often perform double the work of another, though constructed upon the same principles, and driven by the same impelling power. Misled by this circumstance, those who have given an account of the power of their threshing mills, have published merely the number of bolls which they can thresh in a given time, without mentioning the quantity of impelling power, or the number of horses employed to drive them.

Mr. Fenwick, whose labours in practical Mechanics we have already mentioned with commendation, has furnished us with some important information upon this point. He found, from a variety of experiments, that a power capable of raising a weight of 1000 pounds with a velocity of 15 feet per minute, will thresh two bolls of wheat in an hour; and that a power sufficient to raise the same weight with a velocity of 22 feet per minute, will thresh two bolls of the same grain in an hour. From these facts, Mr. Fenwick has computed the following Table, which is applicable to Machines that are driven either by water or horses.

TABLE of the Power of Threshing Machines.

Machinery.

Gallons of water per minute, ale measure, discharged on an overshot wheel 10 feet in diameter.	Gallons of water per minute, ale measure, discharged on an overshot wheel 15 feet in diameter.	Gallons of water per minute, ale measure, discharged on an overshot wheel 20 feet in diameter.	Number of horses working 9½ hours each day.	Bolls of wheat threshed in an hour.	Bolls threshed in 9½ hours actual working, or in a day.
230	160	130	1	2	19
390	296	205	2	3	28½
528	380	272	3	5	47½
660	470	340	4	7	66½
790	565	400	5	9	85½
970	680	500	6	10	95
1	2	3	4	5	6

The first four columns of the preceding Table contain different quantities of impelling power, and the two last exhibit the number of bolls of wheat in Winchester measure which such powers are capable of threshing in an hour or in a day. Six horses, for example, are capable of threshing 10 bolls of wheat in an hour, or 95 in the space of 9½ hours, or in a working day, and 680 gallons of water discharged during a minute into the buckets of an overshot water wheel 15 feet in diameter, will thresh the same quantity of grain.

(455.) *Tube drawing Machines.*—Brass tubes are drawn in two different ways; in one of which the tube is drawn through the gauge, and in the other the gauge is drawn over the tube: the former is generally employed in drawing small tubes, and the latter for the larger kind of tubes. The power employed also in the former being comparatively small, is generally manual strength applied to a system of wheelwork to increase the power, the other is commonly effected by some other first mover.

Drawing brass tubes

The brass or copper tube being first cut of a proper breadth out of a sheet of the metal, is bent round a cylinder into the tubular form, and the two edges securely brazed. A treble is then taken whose external diameter is equal to the internal diameter of the intended tube; the size of the treble or cylinder on which the tube is first bent up is always larger, so that the rough tube passes over the treble on which it is to be drawn quite freely: this latter, which is a solid steel cylinder, is very truly turned in a lathe, except that one end is rather tapering. The tube is placed over this, and is battered over the small end of the treble so as to allow the treble and plate to pass through the gauge or gauge plate. Then when the former of the two methods of drawing is employed, the end of the treble and tube is seized by a strong vice or pair of nippers, and the gauge plate being securely fixed in a frame, the drawing power is applied and the tube and treble are thus forced through the gauge, the tube stretching round the gauge plate as it gets compressed in its passage. Having passed through a small blow struck upon the end of the treble, remove it from the inside of the tube. The latter is then placed in a lathe and its rough ends removed by a parting tool, and the tube is com-

Manufactures.

pleted. In the process above described, the drawing is generally horizontal, the barrel carrying the chain is also placed horizontally, which is turned by a winch carrying a fly wheel and proper wheelwork to increase the power.

In the larger tubes the gauge is, as above stated, drawn over the tube instead of drawing the tube through it as in the above; and generally in this case, the drawing is vertical, that is, the treble with the tube is placed on its end vertically, the small end uppermost, and the tube turned over the end, and well battered down about the upper small part so as to allow the gauge to pass over. The drawing power is then applied to the gauge itself, which is drawn over the tube from the top to the bottom, the tube stretching downwards as the operation proceeds.

We have not thought it necessary to give a drawing of either of these Machines, which may easily be comprehended; and of course the nature of the power employed, and of the Machinery for increasing it, are perfectly indifferent to the operation, so that there be sufficient power for the purpose.

Sometimes, both for cheapness and for strength, a tube of iron is covered with a brass tube instead of being all brass. In these cases the brass tube is drawn over the iron tube, the latter being placed over the treble, which being removed, the brass remains in contact with the iron, and forms with it externally a perfect tube or cylinder of brass.

Reed-making Machine.

(456.) *Machine for making weavers' reeds.*—In the operation of weaving, the several threads of the warp are passed through an apparatus to keep them spread to their proper breadth, and which is also used for driving up each successive thread of the waft to its proper degree, according to the nature of material being manufactured. The apparatus here alluded to is called in Lancashire, Yorkshire, and other Northern Counties, a *reed*, but in many parts of England it is denominated a *slay*. Whence the latter term is derived it is not easy to conjecture, but the former no doubt owes its origin to the material formerly used, viz. bamboo or reed. In some Manufactures three or four threads of the warp are passed through between each two adjacent reeds; in others more or less; consequently, the closeness of reeds may be easily imagined in very fine stuffs, silks, muslins, &c.; and since the introduction of these fine Manufactures thin stripes of iron, steel, or brass have been substituted for the original reeds, but the name has been retained.

When this part of the weaver's loom was made of reed, and by hand, the process was as follows: a bamboo or reed was cut up into lengths between the joints, equal to the proposed breadth or depth of the reed. These were again split into thin pieces, and cut down between two fixed sharp knives or steel edges to their proper thickness, and rendered perfectly smooth. A piece of cane or wood a little exceeding the length of the reed was split up the middle, and also smoothed, and made of uniform thicknesses, and these were placed between supports something like the puppets of a lathe, at such a distance from each other as to admit the reeds, breadthwise, between them. Another cane was submitted to the same treatment, and placed below the first, and parallel to it, at a proper distance, according to the intended depth of the reed; and one of these puppets having an adjustment, these two double canes were brought to a considerable state of tension, and thus ren-

dered perfectly straight. The reeds were now introduced by hand between the open canes, a wax thread passed round each both at top and bottom, each one being driven as close to the preceding one as the thread would admit; and, lastly, any irregularity in the lengths of the reeds, which in this way projected a little above or below the bound cane, were cut down level with it by proper tools. It should also have been observed that two rather broad pieces of thin wood were introduced, one at the beginning and another at the finishing of the operation, to give to the reed when completed a certain degree of stiffness.

After finer works were introduced it was found difficult, if not impossible, to cut down reeds sufficiently thin, and this led to the introduction of steel and brass slips; but the operation was still performed by hand till very recently. A Machine is now employed for the purpose, which is extremely rapid in its performance, accurate in its operation, and altogether one of the most admirable pieces of mechanism it is possible to conceive.

The metal strips which form the reed are received in the form of wire properly annealed. This wire is placed between rollers, and flattened in one long strip of the proper breadth and thickness; it then passes through another Machine, to have its edges smoothed and dressed; in this state it is beautifully uniform, smooth, and bright. It is now placed on a reel near the reed Machine ready for use. The reed, as above described, when made by hand, was placed horizontally, but here the sides are placed vertically; the flattened wire is first introduced by hand, after which every thing else is performed by the Machine itself, which seizes the strip of metal, passes it between the open sides, and cuts it to its proper length; by another apparatus the thread, which lies between the reeds, performs a revolution, and is pressed to its proper bearing, when the Machine again brings the metal forward another length, cuts it off, the binding is again repeated and closed, and so on, with a rapidity and accuracy which no hands could possibly execute. The Machine we have seen is worked by steam power, but as great force is not requisite, at least in the actual construction of the reed, it might be worked by hand, or by any other means at the pleasure of the maker.

(457.) *Weighing Machines.*—Scales and weights, steel-yards and balances of all descriptions may be considered as properly falling under this head; it is not, however, intended to enter upon a description of these, but merely the larger sort of engines for weighing waggons and their loads, as hay, corn, coals, &c.

Some years back nearly every market town had its weighing house, something resembling a town gateway, so that a waggon might be driven in, the horses taken out, and the waggon with its load weighed; and then, the load being delivered, the waggon was again weighed and the difference was the weight of the hay, corn, or coals. The Machine commonly used in these weighing houses was a long and strong steel-yard in a room above the gateway or passage, a chain was passed under the waggon, and by a crane or crab the waggon was raised from the ground and then balanced as any smaller load may be with a less powerful apparatus. These weighing houses, however, have been long getting out of use, but the writer remembers one in a town in Norfolk forty years ago: it was removed about that time, and he does not recollect having seen one since. The Machine which succeeded to these weighing

Machinery.

Weighing Machines
Pl. xxxv.
Fig. 6, 7.

Manufactures.

houses are shallow recesses sunk in the ground and covered with a platform level with the surface of the road on which the waggon is driven, and weighed by an apparatus provided for the purpose. One of these Machines is represented, plate xxxv. fig. 6, where K L M N is a rectangular box, which has a platform lid or cover, of a size sufficient for placing on it the wheels of a cart or waggon. The box is about a foot deep, and is sunk into the ground till the platform cover is even with the surface. In the middle of the box is an iron lever supported on the fulcrum pin $i k$, formed like the nail of a balance, which rests with its edge on arches of hardened steel firmly fastened to the bottom of the box. The lever goes through one side of the box, and is furnished at its extremity with a hard steel pin $l m$, also formed to an edge below. In the very middle of the box it is crossed by a third nail of hardened steel $g h$, also formed to an edge, but on the upper side. These three edges are in one horizontal plane, as in a well-made balance.

In the four corners A A', E, E' of the box are firmly fixed four blocks of tempered steel, having their upper surfaces formed into spherical cavities, well polished and hard tempered. A B C D E represents the upper edge of an iron bar of considerable strength, which rests on the cavities of the steel blocks in A and C, by means of two hard steel studs projecting from its under edge, and formed into obtuse-angled points or cones. These points are in a straight line parallel to the side K N of the box. The middle part C of this crooked bar is faced with hard tempered steel below, and is there formed into an edge parallel to A E and K N, by which it rests on the upper edge of the steel pin $g h$, which is in the lever. In a line parallel to A E, and on the upper side of the crooked bar A C E, are fixed two studs or points of hardened steel B and D projecting upwards above half an inch. The platform cover has four short feet like a stool terminated by hard steel studs, which are shaped into spherical cavities and well polished. With these it rests on the four steel points B, B', D, D'. The bar A C E is kneed in such a manner vertically that the points A, B, D, E, and the edge C, are also in a horizontal plane. These particulars will be better understood by looking at the elevation in fig. 7. What has been said of the bar A C E must be understood as also said of the bar A' C' E'.

Draw through the centre of the box the line $a b c$ perpendicular to the line A E, B D. It is evident that the bar A C E is equivalent to a lever $a b c$, having the fulcrum or axis A E resting with its extremity c on the pin $h g$ and loaded at b . It is also evident that $a c$ is to $a b$ as the load on this lever to the pressure which it exerts on the pin $g h$, and that the same proportion subsists between the whole load on the platform and the pressure which it exerts on the pin $g h$. It will also appear, on an attentive consideration, that this proportion is nowise deranged in whatever manner the load is placed on the platform. If very unequally, the two ends of the pin $g h$ may be unequally pressed, and the lever wrenched and strained a little, but the total pressure is not changed.

If there be now placed a balance or steelyard at the side L K, in such a manner that one end of it may be directly above the pin $l m$ in the end of the lever E O F, they may be connected by a wire or slender rod, and a weight on the other arm of the balance or steelyard may be put in equilibrio with any load that can be laid on the platform. A small counterpoise being first hung on

to balance the apparatus when unloaded, any additional weight will measure the load really laid on the platform. If $a b$ be to $a c$ as 1 to 8, and E O is to E F also as 1 to 8, or if a common balance be used above, 64 pounds on the platform will be balanced by one pound in the scale, and every pound will be balanced by one-fourth of an ounce. This would be a very convenient proportion for most purposes, as it would enable us to use a common balance and common weights to complete the Machine; or it may be made with a balance of unequal arms, or with a steelyard.

Some have thought to improve this instrument by using edges like those of the nails of a balance instead of points; but unless made with uncommon accuracy, they will render the balance very dull. The small deviation of the two edges A and C, or of B and D, from perfect parallelism to K N, is equivalent to a broad surface equal to the whole deviation. We imagine that, with no extraordinary care, the Machine may be made to weigh within $\frac{1}{2000}$ th of the truth, which is exact enough for any purpose in commerce.

It is necessary that the points be attached to the bars. Some have put the points at A and E in the blocks of steel fastened to the bottom, because the cavity there lodged water or dirt, which soon destroyed the instrument with rust. But this occasions a change of proportion in the first lever by any shifting of the crooked bars: and this will frequently happen when the wheels of a loaded cart are pushed on the platform. The cavity in the steel stud should have a little rim round it, and it should be kept full of oil. In a nice Machine a quarter of an inch of quicksilver would effectually prevent all these inconveniences.

The simplest and most economical form of this Machine, is to have a balance or second steelyard; and to make the first steelyard E O F a lever of the first kind, viz. have the fulcrum between O and F, and allow it to project far beyond the box. The long or outward arm of this lever is then divided into a scale of weights, commencing at the side of the box. A counterpoise must be chosen, such as will, when at the beginning of the scale, balance the smallest load that will probably be examined. It will be convenient to carry on this scale by means of balance-weights hung on at the extremity of the lever, and to use but one movable weight. By this method the divisions of the scale will have always one value. The best arrangement is as follows: place the mark o at the beginning of the scale, and let it extend only to 100 if for pounds, or to 112 if for hundred weights, or to 10 if for stones; and let the balance-weights be numbered 1, 2, 3, &c. Let the lowest weight be marked on the beam: this is always to be added to the weight shown by the operation. Let the balance-weights stand at the end of the beam, and let the general counterpoise always hang at o . When the cart is put on the platform, the end of the beam tilts up. Hang on the heaviest balance-weight that is not sufficient to press it down: now complete the balance by sliding out the counterpoise. Suppose the constant load to be 312 pounds, that the counterpoise stands at 86 and that the other weight is 9; we have the load = $986 + 312 = 1298$ pounds.

The most simple weighing Machine for roads, is one recommended by the late ingenious Mr. Tredgold, but we are not aware it has been hitherto put in practice. This author from the numerous experiments he made on the elastic power of iron and steel, saw in their extreme

Machinery

Manufac-
tures.

uniformity of action, while the elasticity was not injured, the means of applying this property to the purposes of a weigh-bridge, whereby without any other apparatus the weight would be ascertained by the amount of deflection of the bar or bars supporting the platform. He has not pointed out any particular method of putting the idea into practice, but the means are so simple, that any person of common ingenuity could not fail of applying them in any case where such a Machine should be required, arranging the bearing points according to circumstances. Of late years weighing Machines of a smaller kind, as substitutes for common scales and weights for domestic and other purposes, have become exceedingly numerous. These, however, can scarcely be considered to belong to the present Treatise. Several of this kind are described under the article Balance, in our general alphabetical arrangement.

Mills.

Mills receive denomination, first, according to the power by which they are put in motion; and, secondly, according to the processes in which they are employed: according to the first classification we have hand-mills, tread-mills, horse-mills, and wind and water-mills, the general nature and construction of which have been already explained in section 80, *et seq.* It remains now to describe them according to the nature of the work they are intended to perform; but we shall confine our description to those simple processes only in which the object is crushing, grinding, or pulverizing; for although the denomination of Mill is given to several other Machines, yet we think it improperly applied. (See section 319.) The latter kind of Machines will, therefore, be given under the process or manufacture in which they occur in the second part of our Treatise.

Process of
barking.

(458.) *Bark-mill.*—Before attempting to describe this Machine, it may be well to offer a few remarks on the nature and qualities of bark, the process of barking, the drying and preparation it undergoes to render it in a proper state for being ground or torn by the mill. In the year 1604 an Act of Parliament was passed which prohibited the use of any but winter-hewn oak for the Royal Navy, which Act was repealed in 1808; and since that time it has been customary in this Country to fell the oaks, or at least to perform the operation of barking, in the month of May, as at that season the bark is more readily separated from the tree, in consequence of the rising of the sap; but the value of the timber is considered to be thereby deteriorated, and is by many persons supposed to be the cause of that disease in timber called the dry rot, which was so fatal during the war to the ships of the British Navy. Du Hamel, in his highly useful Work, *Sur l'Exploitation du Bois*, has some valuable remarks on this subject; see also Barlow's Essay on the strength of timber. Dr. Darwin, likewise, in his *Phytologia* remarks, that as the sap rises in all deciduous trees during the vernal months to expand their foliage, though, probably, in greater quantity in some trees than in others, it must consist not only of sugar and mucilage as in the maple and birch, but of various other ingredients in different trees, as appears from the taste of their young leaves, which has not been sufficiently attended to; and as some of these reside in the roots and in the sap wood, so others of them, perhaps, may reside in the bark, where they have been deposited during the preceding Summer, and become liquefied by the warmth of the Spring, or dis-

solved with the moisture, and conveyed upwards to the opening buds. Whence it is evident, he considers, that the bark of trees should be taken off for use in Winter or in the early part of the Spring before the buds begin to expand; as then a portion of these nutritious juices, of whatever nature they may be, is expanded on the young leaves, which generally possess the taste and qualities of the bark, although in a less degree. It may, nevertheless, be observed, that all these astringent or other qualities may reside in the alburnum of the trunk or roots of all perennial vegetables as well as in their barks; because the young leaves which pullulate on decorticated oaks have the same bitter flavour as the leaves of those which have not been decorticated, which may in part be derived from the bark of the root that is still in the ground, and be carried up the vessels of the sap wood to the new buds. Hence the bark of oak trees should be taken off during the Winter; but when the sap juice residing or ascending in the vessels of the alburnum becomes more liquefied by the warmth of the Spring, or is mixed with moisture, and pushed up with great force by the absorbent vessels of the roots, it oozes out in some degree between the alburnum and the bark, and thus the bark becomes much more easily separated from the tree; whence this business, as has been already observed, is done more readily in the Spring. As at this time the process of germination of the buds commences, which extracts in some measure the virtue of the bark, it is advisable that the peeling should take place immediately this facility appears, whether the tree be cut down or not, as the process of germination continues on new-felled trees while they lie on the ground.

The tool commonly made use of for this purpose is either made of bone or iron. If of the former, the thigh or shin-bone of an ass is preferred, which is formed into a two-handed instrument by a handle of wood fixed at the end, when used for the stem or larger boughs. This edge, once given by the grinding-stone, keeps itself sharp by the wear which afterwards takes place in the operation.

The method of drying bark is generally by setting it in a leaning posture against poles lying horizontally on forked stakes; but in wet seasons, or when the ground is naturally moist, it is laid across a line of top-wood, which raises the bark about a foot from the ground. By this practice no part of the bark is suffered to touch the earth, and it is, perhaps, upon the whole the best method in all seasons and situations. When sufficiently dried it is laid up in houses, or piled in stacks, to be sold to the tanner.

The quantity of bark consumed in the manufacture of leather in England amounted, in 1821, to 117,040 tons, of which 90,000 were imported; the remaining 27,000, which is less than a quarter of the whole consumption, being all that were contributed by England.

Having offered these few remarks relative to the bark itself, we may proceed to describe the bark-mill which is used by tanners for the purpose of tearing or grinding the bark into small portions, in order that the tanning property, or *tannin*, may be more readily extracted from it. Various methods are employed for this purpose. Horizontal and vertical stones are sometimes used; in others, the bark is simply passed between two rollers, which have grooves in their circumferences; in which case the bark is not ground to powder but merely bruised.

(459.) A patent was granted to Mr. James Weldon of

Machinery.

Manufactures.

Weldon's bark-mill. Pl. xxxvi. Fig. 1.

Lichfield, in 1797, for a mill for grinding bark, which is still very commonly adopted. Pl. xxxvi. fig. 1, is an elevation of this mill. A and B are pieces of timber connected with the sides of the mill house which support the Machinery. E is a cast iron shaft, which has a bearing at its upper end in a plumber block attached by bolts and nuts to the beam A. The shaft C has a bevelled wheel E E at the upper part, which engages in a similar one on the horizontal shaft F, by which motion is conveyed to the mill. This shaft may be put in motion by a steam engine, a horse or water-mill, or any kind of mover. When conveniently situated, tanners sometimes employ a wind-mill for the purpose, which is of course less expensive; but it is not so certain of producing a regular supply, and is not therefore very frequently adopted. G is a cylindrical body forming the internal part of the mill which is firmly attached to the vertical shaft C; it is made either of wrought or cast iron, and upon its surface, which is the inner grinding surface of the mill, are formed two rows of teeth, of which the upper ones H H serve to break the bark, and the lower ones K K, which are smaller and more numerous, to grind it. The lower part of the vertical shaft, which projects beyond the conical part G, works in a movable brass step L, in order that it may be raised or depressed, according to the nature of the substance to be ground, or to the degree of fineness required. This brass step slides in a groove or mortise in the cross bar R of the lower framework, and is very accurately fitted, in order that it may have no lateral motion. M is a screw which works in a nut let into the cross beam T, and is turned round by a handle H, so that by this means the step is readily raised or lowered when required.

S S is a circular piece of cast iron, the lower part of which is made conical, and is firmly attached to the uprights Q Q by bolts and nuts. Upon its inner surface are formed teeth, which are similar to and work against those on the piece C, and perform with them the grinding process. These teeth are made at an angle with the vertical axis, and meet the inner teeth, which are made at a similar angle, but the reverse way, after the manner of a pair of scissors, by that means cutting and tearing the bark to pieces, which, when reduced into sufficiently small particles, falls through into a wire sifter which separates the finer and coarser parts of the powder to any degree that may be required.

Chapman's bark-mill. Fig. 2.

(460.) Fig. 2 is a representation of a mill for tearing and crushing bark, invented by Mr. Chapman of Yorkshire, in which the process is performed by horizontal rollers. The view shown in the plate is an elevation of the mill, with the front side of the framing removed, (in order to show the interior construction.) • Motion is communicated to the mill by a spur wheel attached to the horizontal shaft B. Upon the same shaft is a barrel or roller C, termed the rag barrel, which has twenty rows of plates or more on its circumference, according to the power required; these plates are laid to overlap each other, in order that they may form cutting edges. D is a smaller roller, the circumference of which is formed in a similar manner, but with the cutting edges turned in the contrary direction: this roller is put in motion from the spur wheel by two pinions, in order that it may be turned in an opposite direction and at a greater velocity. by this means the cutting edges of the rollers meet, and the bark being placed between them is of course torn and cut to pieces: d is a screw which serves to adjust the distance of the rollers; it has a bearing in the upper

part of the framing, and in a lug or projecting piece cast upon the lower plate of the plumber block in which the axle of the roller D revolves, and thus when turned round it causes a lateral motion to be given to the roller C.

The bark after passing these rollers falls upon the grinding plate D where it is further reduced. This plate is attached to a framing of cast iron which rests upon the cross bars E E, and may be adjusted in both a vertical and horizontal direction, by means of screws in the sides of the framing and in the part upon which it bears; by this means the rollers may be set so as to grind the bark to any degree of fineness that may be required. As the rag barrel is liable to become at times clogged with bark, a wheel G, with spikes on its surface, is made to revolve just clear of the circumference, which gathers the bark and keeps the barrel clean.

H is a spout which receives the bark when ground, and conveys it to the basket k; it is afterwards passed through a cylinder composed of wires of different degrees of fineness, which is put in motion by any means from the main shaft. The dust as it passes down the cylinder falls through into two bins, the upper one to receive the fine dust, and the lower one the coarser dust usually termed *hand dust*. A considerable quantity of a very coarse description, which cannot pass through the wires, falls out at the lower end of the cylinder: this is generally passed again through the mill to be further reduced.

(461.) Mr. Bagnall, of Worsley in Lancashire, took out a patent for a bark-mill, in which the process of grinding was performed by horizontal millstones. The bark was first placed upon a grating, where it was chopped into small pieces by knives attached to long levers; these levers were suspended upon pivots at about a quarter of their length, and were raised by ropes at their extremities, so that when relieved they fell with considerable force upon the grating, and in this way reduced the bark until sufficiently small to pass through the grating, when it was received in a trough which conducted it to the millstones.

The powder which came from the stones was caught in an inclined riddle or sieve, through which the fine dust escaped, while the coarser portions passed down and were received in a trough, where they underwent a further process of being beaten and bruised by a hammer to render them fit for the tanner.

This mill did not, however, possess the advantages expected by the patentee; the millstones are liable to be clogged from the fibrous nature of the bark, and it has, in consequence, not been much adopted. It was provided with an apparatus for scraping off the hair and extraneous matter from the hides, technically termed *beaming*, which very commonly forms a part of bark mills. The hides are placed upon a kind of wooden carriage, which is rendered easily movable upon a tram road, and a knife attached to a beam above, having a reciprocating motion from the Machinery, passes along the surface and rubs off the hair. The sliding rod or beam to which the knife is fixed is usually inclined about ten degrees from the horizon; it receives its motion at the upper end from the Machinery by means of a crank, and the other end rests upon a suspended roller, which may be raised so as at any time to bring the knife clear of the hide. When the beam arrives at the bottom of the stroke it engages a lever having an arch head, which turns upon a pivot at its lower extremity, and which

Machinery.

Bagnall's bark-mill.

Manufac-
tures.

returns with the beam and raises it clear of the hide, so that the operation of scraping is performed in the descending stroke only. When the beam arrives at the top of the stroke, the lever disengages itself and falls back into its original position to be again taken up by the next stroke. The scraping knife is usually attached to a string, which allows it to yield to any irregularities in the surface of the skin, and prevents damage to the hides, which otherwise is liable to occur. The hides are readily shifted by the carriage when sufficiently scraped, and a new portion of the surface is prepared for the action of the knife during the return of the beam.

Scouring of tanned leather for the use of the currier may be done by the same Machine simply by removing the knife and fixing a stone with a push, either before or after it, in its place. For more on this subject, see the article Tanning.

Quantities
of bark im-
ported and
exported.

(462.) *An Account of the Quantities of Bark for Tanning imported into and exported from the United Kingdom, and cleared for Consumption, together with the Rates of Duty and Net Amount of Revenue in each Year, from 1820 to 1831, both inclusive.*

Years.	Importations.	Exportations.	Consumption.	Rates of duty per cwt.	Net Revenue.
	Cwts.	Cwts.	Cwts.	s. d.	£.
1820	319,342	..	316,790	0 8	10,742
1821	424,091	130	422,649	..	14,062
1822	662,521	20	662,375	..	21,843
1823	1,088,535	400	1,076,631	..	36,159
1824	960,468	..	964,829	..	32,414
1825	1,017,250	..	1,012,065	{ New South Wales and de- pendencies free. Other parts.	33,956
1826	545,610	40	550,542	0 8	19,745
1827	807,315	4	807,190	..	29,308
1828	810,581	..	809,150	..	29,903
1829	1,013,684	1,143	1,007,938	..	36,619
1830	1,007,928	1,390	997,665	..	35,222
1831	970,523	2	964,379	..	32,727

An additional duty of one-fifth on the existing rates of duty has been levied on bark in common with other goods imported in ships belonging to the Kingdom of the Netherlands, under Order in Council 30th January, 1826.

Cement-mill.

Cement-
mills.

Cement-mills are employed to reduce certain stones or concretions of clay containing veins of calcareous matter into the state of powder in order to form cements. The same description of mills are also employed to grind puzzolana, a volcanic mineral exported from Italy, which, when added to mortar, gives it the property of setting under water.

Parker's
cement.

(463.) *Parker's cement.*—The principal cement of English production, is thus denominated from the name of the inventor, Mr. James Parker, of Northfleet in Kent, who took out a patent for this important invention in the year 1796. It is sometimes also called Roman cement. The patent consisted in employing certain mineral productions in the formation of a cement, which should be much stronger and harder than any at that time prepared by artificial means, and which also possessed the property of setting either in or out of water in ten or twenty minutes after being mixed. The stones previously to being ground are broken into small fragments about

the size of a walnut by hammers, and then burned in a kiln or furnace with a heat nearly sufficient to vitrify them. The stones are of so soft a nature that the operation of breaking is usually performed by women or children, who by the aid of a small hammer can readily reduce them to the required size. When burned, they assume a red appearance and are a little further softened; they are then prepared for the process of grinding.

(464.) *Puteolean powder*, now denominated *puzzolana*, is a light porous friable mineral of a red colour: it was discovered by the Romans at the town of Puteoli, from which it takes its name. It is generally supposed to derive its origin from the concreted volcanic ashes thrown out from Vesuvius, near to which mountain the town of Puteoli is situated, and seems to consist of a ferruginous clay calcined by the action of the volcano. When mixed with common mortar, it not only acquires a remarkable hardness in the air, but becomes as firm as stone even under water.

Puzzolana was first brought into this Country at the time Westminster bridge was building, by a merchant at Plymouth, who expected to dispose of it to advantage for that work. He, however, failed in his speculation, as neither the Commissioners nor Engineers would make a trial of it; and it remained by him undisposed of until Mr. Smeaton tried its efficacy as a cement for the Eddystone lighthouse, and found it to answer so well that he purchased the whole of it. Since that time, it has been exported in considerable quantities from Civita Vecchia in Italy, and is now very generally used in all under-water constructions. It arrives in this Country in lumps, which require some preparation previously to being passed through the mill; Mr. Smeaton recommends the following: *viz.* to sift it through two wire sieves, the finer of which should have about seven or eight meshes per inch running. The dust which passes through the fine sieve is fit for use, the remainder must be further reduced in the mill. It is advisable that the larger portions left in the first or coarse sieve should be broken and examined in order to pick out a kind of grey stony matter, as well as other heterogeneous substances that get accidentally mixed with it, which will readily be distinguished from true puzzolana. This grey stone has no cementing quality; it is also difficult to grind.

The part to be ground must then be made perfectly dry either by the sun or by a drying kiln, otherwise it is apt to clog the stones.

(465.) Fig. 1, pl. xxxvii. is a side elevation of a mill erected in his Majesty's Dock-yard at Sheerness for the purpose of grinding cement, worked by a twelve-horse power steam engine. A A A are the walls of the engine house and mill, R R R the roof, and B B the main shaft of the engine from which motion is given to the different parts of the Machinery.

The cement previously to being ground is passed between two iron rollers, one of which is seen at C in the figure; this roller is put in motion when required by means of a clutch *p p*, from a spur wheel on the main shaft, which engages the wheel E E and communicates its motion by the spur wheel F F to a similar one on the shaft of the other roller, so that the rollers meet each other moving at the same velocity. The lumps of cement are placed in a hopper *h' h' h'*, and are conducted by a trough *t t* to pass between the rollers, in which process they are reduced into small fragments.

Cement-
mill at
Sheerness
described.
Pl. xxxvii.
Fig. 1.

Manufac-
tures.

The cement is caught in a sack as it comes from the rollers, and is conveyed to the upper floor of the mill, by aid of Machinery, termed sack tackle; this consists of a pulley *a a*, which may be put in motion by a similar one *b b* on the main shaft when required by a lever, (not seen in the figure,) which tightens the rope *r r* and thereby causes sufficient friction to carry round the upper pulley, so that in the ordinary state of the mill the lower pulley alone revolves. A rope, to which the sack is attached, passes round a drum on the spindle of the upper pulley, and is consequently taken up with the sack when the Machinery is put in gear.

The grinding is performed by two horizontal millstones which are inclosed in a wooden case *G G* to prevent the escape of the dust; the lower one is stationary and well bedded upon the beams *e e*, and the upper one is attached to a spindle which is put in motion by the Machinery. The mill represented in the drawing contains two pair of stones, one being placed on each side of the cog wheel *H H*. This cog wheel puts the upper stone of each pair in motion by a spur wheel which is attached to a vertical spindle passing through a hole in the lower stone, and receives its motion from the main shaft by a bevelled wheel *m m*, which engages a similar one *n n* on the lower end of the vertical shaft *h h*. The millstones have grooves or channels on the face of them cut obliquely from the circumferences to about an inch or an inch and a half on one side of the centre, but in the reverse direction in the upper and lower stone, so that when in motion the edges are continually meeting each other, and by that means crush and break the cement, which when reduced to powder passes along them to the circumference whence it escapes into a trough. The stones make about a hundred and fifty revolutions in a minute; they are very commonly made of stone from the Peak of Derbyshire. French burrs, however, answer the purpose best, particularly if it is required to grind puzzolana; for though it may be done by other kind of stones, yet as it is mixed with flinty matter which cannot be all picked out, no other stones will stand the service for any length of time. The construction and manner of cutting the grooves is exactly similar to that of corn-mills, to which article we beg to refer the reader who is desirous of more particulars on this subject.

The cement when it arrives at the upper floor from the rollers is emptied into a large hopper *K*, from which it proceeds by a spout to a smaller one *L*, and thence into a trough *M* which conveys it to a hole in the upper stone. The trough is inclined, and is kept in continual motion by a small iron cross *g*, which revolves with the upper stone and keeps tapping it so as to cause a regular supply to pass down to the stones according to their velocity. The cement when ground passes out at the circumference of the stones into the spout *k* as above described, which conveys it to two sieves, (one of which is seen at *ll*,) in order to separate the fine dust from any hard lumps which may have been imperfectly ground. The sieves receive a rapid reciprocating motion from the Machinery by a rod attached to them and to a small crank *r* upon the vertical spindle *p p*, which receives motion from the cog wheel *H H* by a small spur wheel or pinion fixed upon it. This serves more effectually to separate the fine dust which passes through into sacks for use.

(466.) *Mortar-mill*.—The part marked fig. 2 in the drawing, is a mill for the purpose of grinding calcined

limestone or chalk into powder in order to form quick or hot lime. This is very commonly termed a *mortar-mill*. The lime in this state is preferable to slacked lime in the formation of cements for many situations in building, as it causes them to set quicker. The proper application of these different states of lime will be better treated of when we speak of the composition of cements in a subsequent part of this article. At present we shall confine our remarks to the mechanism of the mill.

A A is a vertical shaft or spindle which has a bearing at its upper end in a plumber block attached to the cross framing, and at the lower end in a brass step which is let into the cast iron plate *B B*. To this is fixed at right angles a horizontal shaft *c* upon which the mill stones *D D* revolve, consequently when the shaft is put in rotation from the engine by the bevelled gear *a a b b*, these stones have two motions, one on their axles and the other round the vertical shaft *A A*. The lime to be ground is placed on the cast iron plate *B B*, which is very firmly bedded upon timbers, and the stones pass over it grinding and crushing it into a small powder. The stones are commonly fixed at different distances from the vertical shaft so as to describe two different tracks on the cast iron plate. Curved pieces of iron termed rakes are attached to the shaft and revolve just clear of the surface of the plate; these serve to collect the lime in the track of each roller in order that it may pass over it. This description of mill is sometimes used for grinding Parker's or Roman cement. The horizontal stones are, however, very much preferred, as they produce a finer powder which is essential to its property of setting quickly.

There are in addition to the above other mills used in the formation of cements for the purpose of mixing the ingredients well together, commonly called *Pug-mills*. The common method of mixing lime and sand by the shovel is very imperfect, and to this may be attributed the badness of the mortar of our common edifices.

(467.) *Pug-mills* are of such simple construction, and are so varied according to circumstances, that it would be useless to describe them; a few general remarks, therefore, are all that seems necessary to be given on this head.

The most complete form of this mill is that which was generally made use of by Smeaton, viz. the running stones, which do not differ from the one above described for grinding quicklime, except that it was put in motion by a horse which walked round at the extremity of a long lever attached to the vertical shaft.

In the common pug-mill, a circular trough is made in the ground, with a post firmly fixed in the middle, a long lever is attached to it so as to be movable, at the end of which a horse walks round. The lime and sand are thrown into the trough, and are mixed up by a kind of rake which is attached to the lever.

Pug mills consist sometimes simply of a barrel fixed firmly in the ground, having a vertical spindle with spokes or projecting pieces attached to it, turned round in it, which mixes up the mortar. In fact, their operation is so simple that the ingenuity of the builder will always devise a means of effecting his purpose according to the situation and circumstances in which he is placed.

Composition of Cements.

(468.) Before entering into a description of the various cements employed in the construction of buildings, it is

Machinery
Mortar-
mill.
Fig. 2.

Pug-mill

Manufac-
tures.

Of lime.

desirable to make a few remarks on the nature and properties of lime, a mineral which composes a greater or less proportion of almost every cement, and seems indeed essential to their cementing property.

(469.) *Of lime.*—This substance is usually found combined with carbonic acid in the form of chalk, marble, limestone, and sea shells, from which the carbonic acid is driven off by the process of burning them in kilns.

There are two modes in which lime acts as a cement: in its combination with water, and in its combination with carbonic acid. When quicklime, which is the produce of the kiln after burning the limestone, is made rapidly into a paste with water, it soon loses its softness, and the water and the lime form together a solid coherent mass termed hydrate of lime, which is composed of about one part of water to three parts of lime.

When quicklime is taken fresh from the kiln, and a due quantity of water thrown on it, it splits with noise, swells, gives out a burning slightly caustic vapour, and falls into a thick creamy mass. This operation is termed slacking. When lime is slacked and mixed with sand as in common mortars, it first solidifies as a hydrate, and is then slowly converted into carbonate of lime from the atmosphere. Mr. Tenant found that mortar of this kind had in three years and a quarter regained sixty-three per cent. of the quantity of carbonic acid, which constitutes the definite proportion in carbonate of lime. The hardness of the mortar in very old buildings depends upon the perfect conversion of all its parts into carbonate of lime. The purest limestones are best adapted for making this kind of mortar: the magnesian limestones make excellent water cements, but act with too little energy upon carbonic acid to make good common mortar.

The Romans, according to Pliny, made their best mortar a year before it was used, so that it was partially combined with carbonic acid before it was employed.

Burning
lime.

In burning lime, there are some particular precautions required for the different kinds of limestones. In general, one bushel of coal is sufficient to make four or five bushels of lime. The magnesian limestone requires less fuel than the common limestone. In all cases in which a limestone containing much aluminous or silicious earth is burned, great care should be taken to prevent the fire from becoming too intense; for such lime easily vitrifies in consequence of its affinity for silica and alumina. And as in some places there are no other limestones than such as contain other earths, it is important to attend to this circumstance. A moderately good lime may be made at a low red heat, but it will melt into glass at a white heat. In limekilns for burning such lime, there should always be a damper.

Mr. James Frost of Finchley, in the County of Middlesex, took out a patent for an improved process of calcining calcareous and other substances, which consisted in employing retorts or furnaces which excluded the atmospheric air, and in removing the substance when sufficiently burned into vessels to cool, which were also air tight.

This is certainly a considerable improvement upon the common method employed in limekilns, as a considerable quantity of carbonic acid is absorbed during the cooling.

In general, when limestones are not magnesian, their purity will be indicated by their loss of weight in burning: the more they lose the greater is the quantity of

calcareous matter they contain. The magnesian limestones contain more carbonic acid than the common limestones, and all of them lose more than half their weight by calcination.

The different kinds of lime used in the composition of mortars and cements for buildings, are commonly distinguished by the terms *fat* and *lean* lime; the former, when quick and reduced to powder, absorbing so much water in slacking as to triple its bulk; the latter increasing only its own bulk or one and a fifth; but between these extremes there are so many intermediate qualities of limestones, as to render it difficult to draw a line of distinction between them. This denomination of lean lime has been since applied exclusively to all those species which have the property of hardening or setting under water.

(470.) M. Vicat, engineer in the *Corps Royal des Ponts et Chaussées* of France, made a set of very interesting experiments on lime, mortar, and water cements, which were published by the desire of that Corps, and also of the Institute of France. He gives the name of *hydraulic limes* to those which, when properly burned, have the property of hardening in a short time under water, and of *common limes*, those which have not that quality; *fat limes*, those which when calcined and plunged under water absorb in slacking from 260 to 360 per cent. of their weight of water; *middling limes*, those which absorb from 230 to 260; and *lean limes*, those which take up from 100 to 230.

The hydraulic limes are sometimes white or scarcely coloured, but generally they are grey or *clay* coloured. When they are slacked to the consistence of a thin cream and then plunged into water, in setting they part with a portion of the water with which they are combined. On the other hand, when slacked only to the thickness of a stiff paste and then immersed in water, they absorb an additional portion of this fluid in setting. There is, therefore, a determinate quantity which this kind of lime requires for setting, and this process takes place independently of exposure to air or external circumstances.

Common limes slacked under water take up much more water than they can solidify, and as they have not the power of rejecting what is superfluous, they remain constantly in the state of soft paste, not only under water, but in the pits in which they are slacked, when covered with sand or earth.

There are some limes which have an intermediate quality between the two above mentioned, which acquire some consistence after slacking but without ever setting properly.

The qualities of lime not only vary in different districts, but even in different parts of the same quarry; which will sometimes yield every variety of lime from the most completely hydraulic to that which remains perfectly soft after slacking.

Bergmann, and after him Guyton, have attributed the water-setting property to a small proportion of manganese; Saussure to silex and alumine; Descotils, from the analysis of the limestone of Senorches, to a large proportion of silicious matter disseminated through it in fine grains, and which appears to amount to a fourth of its weight. But, on the other hand, the limestone of Metz, so eminent for its hydraulic qualities, contains only 5 or 6 per cent. of silex; and M. Vicat has ascertained by numerous assays, that iron and manganese are not indispensable to this quality. As there is yet

Machinery

Different
kinds of
lime.Experi-
ments on
cements by
M. Vicat.Water-
setting pro-
perty of
lime.

Manufactures.

much uncertainty on this subject he remarks, "that as in large works it is of the utmost importance to be assured of the quality of the lime employed, it would be better always to make a previous assay of the limestone." For this purpose it may be calcined in a limekiln, or otherwise in a forge furnace fed with charcoal; and when sufficiently burned it may be slacked with water to the consistency of thin paste, and covered with water in any convenient vessel. If at the end of a week or a fortnight the mass of slacked lime has stiffened so as to resist the impression of the finger, it is a proof of its hydraulic quality, but if it remains soft it is only common lime.

The hydraulic limes are useful not only as the bases of water cements, but form excellent mortar for buildings exposed to the air, when mixed up with common sand. It is true that masons prefer the fattest lime for common purposes, but this is easily accounted for, from the much larger proportion of sand they will take up, which is the least expensive ingredient; but it is surprising that Architects have examined the hydraulic limes only in respect to their water-setting qualities, and not as to their use in works exposed to the air.

Vicat's experiments on different modes of slacking.

(471.) M. Vicat's first experiments were made with a view of trying the effects of different methods of slacking lime. The first was the common method, as has been before described. In the second, the quicklime was plunged into water for a few seconds and then withdrawn; it soon began to hiss, split with noise, and fall into powder. This is called powder of lime by immersion; it may be preserved for a long time in this state provided it is kept dry, and does not heat when afterwards slacked by water. We owe this method of slacking to M. de Lafaye, who published it in 1777, as a secret discovered from the Romans.

The third method consists in exposing the quicklime to the gradual action of the atmosphere until it falls into powder. There is a slight evolution of heat during this process, but without visible vapours.

The following is the quantity of water absorbed and the volume of liquid of equally pasty consistence, or cream of lime, produced by the three above-mentioned modes of slacking.

	Weight of water absorbed.	Volume of cream of lime.
100 parts by weight of common fat lime slacked by the first process.	236	310
ditto by the second	131	104
ditto by the third	148	176
100 parts lean coloured hydraulic lime slacked by the first process.	105	137
ditto by the second	71	127
ditto by the third	68	100
100 parts of lean white hydraulic lime slacked by the first process.	110	130
ditto by the second	80	117
ditto by the third	70	108

Upon these results it may be observed that equal quantities of the same lime will give pasty liquids of the same consistence, but with different portions of water, accordingly as one or other mode of slacking is adopted. This, M. Vicat remarks, evidently depends on the degree of continuity which the particles of lime contract by evaporation. The swelling, and superior quantity of water absorbed in the first process, shows that it is in this in which the division of its particles is carried to the highest degree. In confirmation, it may be added, that

VOL. VII.

in all but the perfectly white limes, the colour after Machinery. slacking is deeper by the second and third processes than by the first, resembling, in this respect, vermilion and other coloured substances, whose tint of colour is brightened in proportion as they are more minutely divided. It therefore follows, that in order to compose a mortar made with lime slacked by immersion in water, or by spontaneous exposure to the air, in which the consistence is required to be in appearance the same, as fast and binding as when lime is slacked in the ordinary way, a greater proportion of lime to the other ingredients of the mortar must be employed in the former than in the latter case.

(472.) *On the combination of water with lime.*—When pure lime, slacked to the consistence of cream, is dried in a crucible, it gives a compound termed hydrate of lime. This is white, pulverulent, and attracts the carbonic acid of the atmosphere.

Many trials have shown that the quantity of water employed in the slacking has a great influence on the hardness of the hydrate produced by the evaporation of the superfluous water.

M. Vicat made the following experiments on the quantity of water requisite to give the greatest degree of hardness to the hydrate of lime.

Description of lime.	Parts by weight experimented on.	Parts of water used to slack it.	Number expressing the relative hardness.
Common fat lime . .	100	137	0.126
	100	183	0.222
	100	315	0.068
Hydraulic lime . . .	100	70	0.014
	100	92	0.051
	100	246	0.010

From these experiments it appears that 183 with the first specimen, and 92 with the second, gave the best result.

(473.) In pursuance of these inquiries, M. Vicat tried the relative resistances or tenacity of quadrangular prisms formed of different species of lime, slacked according to the three methods already mentioned; they were of an indeterminate length, but had for their section a rectangle of 1.57 inch base and 0.98 inch height. He exposed them for several days to the rays of a Summer sun, and thus obtained dry hydrates covered with a very thin crust of revived carbonate of lime, which readily scaled off. The breaking force was applied, by fixing the prism horizontally on a block, fastening it by an iron slip, and hanging over the projecting edge an iron spur, supporting a box, the weight of which was gradually increased by a small shower of fine sand until the prism broke.

These experiments gave results of which the following is an abstract.

Description of lime.	Method of slacking.	Number expressing the relative tenacity.	Number expressing the relative hardness.
Common fat limes	1st method	2490	0.1696
	2d ditto	450	0.0713
	3d ditto	1707	0.0850
Hydraulic lime . .	1st method	864	0.0488
	2d ditto	392	0.0446
	3d ditto	245	0.0358

2 z

Manufac-
tures.

From these experiments it appears that with the common fat limes the greatest tenacity was given by the first or common method of slacking; the next, by the third method, spontaneous evaporation; and the last by the second method, which is that of immersion.

That with hydraulic limes the tenacity is greatest with the first method, next in degree with the second, and least with the third.

It is not within our limits to give all the observations and remarks made by M. Vicat during these investigations; we shall add those only with which he concludes this section of his paper.

Deductions
from Vicat's
experi-
ments.

(474.) First. That very fat white limes may form, by the assistance of water alone, bodies as hard as a multitude of natural limestones, particularly when the common mode of slacking is used, and when a firm binding consistence is given to the paste, and nothing opposes its shrinkage on drying.

Secondly. That the action of the air and length of time increases the hardness of the slacking limes exposed to it.

Thirdly. That the hydraulic limes, particularly those which are coloured, give by the action of water only light and soft compounds.

Fourthly. That the action of the air increases their hardness, but not in any degree equal to that which it gives to the hydrates of the fat limes.

Fifthly. That the resistances of these different compounds are not at all proportional to their degrees of hardness.

If it were possible to make moderately large blocks or tables of mere lime and water, the increase of hardness produced by exposure to the air could not be reckoned as any thing, for ten years would not regenerate one-twentieth of an inch in depth. We must, therefore, only take into account the firmness of texture produced by the lime and water alone; and this varies, in the most favourable circumstances, from 2.745 to 3.690, good brick being 5.690.

But the chief difficulty that would arise from the use of hydrate of lime is the great shrinking that takes place as it dries. When prisms are made of it, that do not exceed the dimensions of a very small brick, and are set to dry on a floor, to which they do not adhere, they shrink without cracking, and dry into solid masses, covered, however, with a slight efflorescence which rounds off the angles and corners. But if it were attempted to fill moulds with this material it would dry irregularly, and cleave to the moulds, and would turn out full of cracks and unfit for use. No advantage is got by kneading it before moulding.

The fat limes shrink the most; and more in proportion as they have been more thoroughly divided in slacking. This shrinking will always oppose the use of mere lime as a mortar, unless in works under water, or in thin coatings of stucco, previously made fit for use by long and laborious kneading. Vitruvius, indeed, speaks of light works of the Roman masons made of lime alone, and called by them *albaria opera*: and it is the custom in the East Indies to coat the walls with a fine stucco, made of quicklime, beat up with milk, oil, and other ingredients. It would not be difficult to make thin slabs of mere hydrate of lime, which, when well smoothed and polished on sandstone, would imitate fine white marble, and might be employed in mosaic work.

Water has no action on the hydrates of the hydraulic limes; but it dissolves and decomposes the fat limes.

To show the action of water on the latter, let some balls be made of a slacked fat lime and water, and when dry expose them to the air. In a month or two they will be covered with a hard crust of regenerated carbonate of lime, and will be insipid when the tongue is applied to the surface; but when broken in two, the inner portion will show the causticity of the lime by the well-known acrid taste. If the broken portions are then immersed in a current of water all the inner part will be dissolved out, leaving only the exterior shell of carbonate of lime. Descotils, reasoning from the fact, that during the burning of limestone the silex which may be united with it undergoes such a change as to be rendered soluble in acids, concludes that this substance contracts an intimate union with the lime, and thus makes it less easily acted on by the atmosphere or by water. This observation will very well explain the resistance which the hydrates of hydraulic lime oppose to the dissolving action of water; but it appears not so easily reconcilable to the very weak consistence which they acquire by exposure to the atmosphere.

We add here a Table containing the properties of nine different water limestones analyzed by Smeaton during his experiments to ascertain a proper cement to be employed in the erection of Eddystone Lighthouse.

Machinery.

Properties
of different
British
limestones.

No.	Species of lime-stone.	Proportion of clay.	Colour of the clay.	Reduction of weight by burning.	Colour of the bricks.
1	Aberthaw	$\frac{2}{28}$	Lead colour.	4 to 3.	{ Grey stock brick.
2	Watchet	$\frac{1}{28}$	ditto	4 to 3.	{ Light colour, reddish.
3	Barrow	$\frac{1}{14}$	ditto	3 to 2.	{ Grey stock brick.
4	Long Bennington . . }	$\frac{1}{22}$	ditto	..	Dirty blue.
5	Sussex clunch . . . }	$\frac{1}{18}$	Ash colour.	3 to 2.	Ash colour.
6	Dorking	$\frac{1}{17}$	ditto		
7	Berryton grey lime. }	$\frac{1}{12}$	ditto		
8	Guildford	$\frac{1}{15}$	ditto		
9	Sutton	$\frac{3}{18}$	Brown.		

(475.) On cements exposed to the action of the air, usually termed mortars.—These are composed of a mixture of lime and sand; they are subjected to a number of vicissitudes to which water cements are not liable; they are sometimes in contact with earths of different chemical qualities, exposed at time to the changes of rain, sunshine, frost, and thaw, are seldom in a permanent state of dryness, except in the interior of buildings; whereas water cements have only to contend with one element which undergoes but slight variations of temperature. It is, therefore, to be regretted that the former have not been more attended to by scientific men.

The solidification of common mortar proceeds, according to the hypothesis of Dr. Ure, from the re-formation of the hydrate of lime into the carbonate of lime by its attraction of carbonic acid from the atmosphere. This hypothesis is, however, objected to by M. Vicat; who, although he allows that there is a remarkable affinity of hydrate of lime for carbonic acid, considers that this effect cannot reach far, and can never penetrate into the centre of thick walls, or the mortar of foundation work. It may, however, be observed that the mortar in the interior of thick walls is known to require a very great

On mortars.

Hypotheses
as to the
cause of
hardening.

Manufac-
tures.

length of time before it becomes indurated, and is generally inferior in hardness to that nearer the surface. A fact related by Mr. Smeaton may serve to illustrate this point. Having had occasion to take up a large flat stone of a close grain, which had probably lain above a century at the bottom of a malt cistern, he found that it had been well bedded in mortar, which had become coagulated to the consistence of cheese; but it had so far retained its natural humidity that he was enabled to beat it up to mortar without any addition of water, and afterwards having exposed it to the air, it set to a stony hardness, and appeared as good mortar as any which that part of the country produced.

Several other hypotheses have been given to explain the solidification of common mortars. M. Faujas St. Fond thus expresses himself on this subject: "The water which holds the particles of lime in maceration for a length of time takes possession of the whole of the fixed air (carbonic acid) which is concentrated within it; it then acquires the power of reducing and binding the absorbent earth when wrought up with it, and uniting it to quartz. And as the evaporation of the liquid takes place in a slow and insensible manner, or rather as one portion of the liquid combines with the materials to make water of crystallization, this operation becomes more perfect in proportion as it is longer and more thoroughly elaborated."

This explanation supposes a crystallization, the existence of which it is difficult to prove: when the lime is examined in the fracture of a portion of good mortar, taken up from the foundation of an edifice, shining particles appear which seem to indicate a confused crystallization; but some days of exposure to the air are sufficient to disperse this appearance, and to make the whole return to the common dead white of slacked lime; this deception, therefore, depends on a very small quantity of uncombined water which disappears by spontaneous evaporation. It is well known that if water saturated by carbonic acid is poured into lime water, the mixture first grows turbid, but clears again by a further addition of carbonic acid, which redissolves the precipitated carbonate of lime, and this again falls down by ebullition or slow evaporation. But how is it possible to conceive a similar effect on mortar, the consistence of which is pasty, and which retains no more carbonic acid than the last portions which the fire has not been able to expel from the lime in burning? whereas for this explanation of M. Faujas to be true, it would require the presence of an excess of carbonic acid even more than the raw limestone contained before burning.

A variety of other opinions have been formed by different authors on this subject. Lorient, the inventor of the celebrated Lorient Cement, considered the lime as a simple gauge or matrix, and the sand merely in the light of a foreign body which only increases the bulk of the mixture; but if this were really the case, and if the lime had no chemical action on the silicious grains which it incloses, it is obvious that it would set under water as readily without as with the sand which the mortar contains.

(476.) *On the properties of sand.*—Builders do not agree on the comparative qualities of fossil sand, river sand, and sea sand. Mr. Rondelet is, after Vitruvius, the author to whom we owe the greatest number of particulars on this subject; and he concludes that we cannot form an exact opinion of the goodness of sand from the place whence it is taken, but only from

the colour and the quality of the substances of which it is composed; and he gives a preference in sand of the same species to those samples which have the darkest colour, excepting, however, the yellow.

M. Vicat made, in pursuance of his inquiries on cements, a set of experiments to ascertain the relative resistance presented at the end of a year by different mortars, in which he used the sand of the Dordogne, where the quartz predominates, and which also contains mica, felspar, schorl, and basalt.

The extent of these experiments will not permit us to give them at full length; we shall therefore simply give the remarkable conclusions which he came to from their results.

First. That the samples of lime which when merely wetted without other addition form the most solid bodies, are those which produce the weakest mortars with sand.

Secondly. That quartzose sand does not contribute, as has been generally supposed, to increase the cohesion of every species of lime indiscriminately; but that it is useful to some, prejudicial to others, and has no sensible effect on a third class.

He found that a mortar, composed of common fat lime and eminently silicious sand, was not capable of acquiring any considerable hardness by exposure to the air. It is equally impossible to dispense with the use of sand; for if this species of lime, slacked and used without addition, is capable of hardening considerably by setting, it could not be actually employed in this way, except in very thin layers, and if it were attempted to use it thus as a mortar it would fall in fragments from the trowel. The presence of sand in some degree eludes the entire contraction, by subdividing it into an infinity of partial contractions, which take place in each interstice, formed by three or four contiguous grains: whence the pulverulent appearance, the permeability to moisture, and the weak cohesion which we have so often to regret in the mortar of our common edifices.

(477.) *On the best size of the grains of sand.*—Pliny and Vitruvius recommend that it should be clean, large-grained, and sharp. The sand which is made use of in London is very defective, being composed of round grains, and soiled with a large mixture of clay. Its fineness and smoothness cannot be amended; but by washing it well, the clay might unquestionably be got rid of, which would be a great improvement. Mr. Smeaton has shown by direct experiment that mortar of the best quality, when mixed with a small proportion of unburned clay, never acquires that degree of hardness which otherwise it would have attained.

Screened rubbish and scrapings of roads, consisting chiefly of gravel reduced to fine powder, are also used as substitutes for sand, but with great impropriety.

Mr. Rondelet says in his Treatise that mortar made with too fine sand never acquires the same degree of consistence as that made with moderately coarse sand; but it is probable that this refers only to mortars made with ordinary limes.

M. Vicat, however, did not find in his experiments much difference produced by the size of the grains of sand on the hardness of mortar, the greatest difference not exceeding one-fifth of the whole resistance.

With eminently hydraulic limes he found the order of tenacity to be greatest with fine sand, second with unequal grains produced by the mixture of the fine and coarse sand, and third with coarse sand.

Machinery.

Properties
of sand.

Manufac-
tures.

For the common hydraulic limes the order is: first, mixed sand; second, fine sand; third, coarse sand; and for common limes is, first, coarse sand; third, fine sand.

The conclusion that may be drawn from the results is, that the more the quartz is divided the more intimately it will combine with the highly hydraulic limes, on which it seems to exercise a great chemical action, whilst the reverse seems to take place with the common limes.

The sand used by the Romans is of various descriptions. In their building at Cahors they have used for their mortar a mixture of common sand and gravel, when an abundance of each was at their command; in other parts of France, where the lime is but of a middling quality, they have used only gravel; and in Syria there are examples of various hard ancient Roman mortars composed of very fine sand.

Best pro-
portion of
lime and
sand.

(478.) *The best proportion of lime and sand* in the composition of mortar is a point by no means settled. The Roman builders were accustomed to allow three parts of pit sand or two parts of river or sea sand to one of lime. In general, it may be affirmed, that it will be advantageous to use the largest quantity of sand that can be introduced, preserving the necessary degree of plasticity. Mortar, in which the sand predominates, requires less water in preparing, and therefore sets sooner; it is harder and also less liable to crack in drying than that in which the lime prevails. Smeaton observes, that there is scarcely any lime but what, if well burned and beaten, a load or measure of unslacked lime will take two loads or measures of sand. On pursuing this subject, he found that by good beating the same quantity of lime would take in one measure of tarras three of clean sand, which seems to be the greatest useful proportion; for on a further increase of the quantity of sand, the mortar requires so much more beating to bring it to a proper consistence and toughness, that the labour became of more value than the saving of materials. These observations agree very nearly with the experiments of Dr. Hutton.

Our ancestors have left us a crowd of incontestable examples that they well understood the Art of making cements. M. Vicat, however, considers that the very general notion that the Art is lost is entirely a mistake, and that mortars can be made without the use of puzzolana, at least equal in hardness to the best of the Roman.

A few years ago there existed at Agen the ruins of a bridge, thought to be antique on account of the hardness of the mortar, which was so great that they were obliged to employ blasting to remove the remains of the foundation. This bridge, however, which the lovers of the marvellous were inclined to carry back to the time of the Pelasgi, was built by a Charter obtained from Richard I., King of England, who was at that time master of Agen and a great part of the South of France. The mortar of the bridge of Valentré, built at Cahors in 1400, resembles in every respect, both in the quality of the lime and size and proportions of the sand, that of an ancient theatre whose ruins still remain in the same town at five or six hundred yards from the river.

TABLE showing the comparative Tenacity of different Mortars.

Machinery.

No.	Description of mortars.	Number expressing the relative resistance.	Pressure upon a square inch surface.
		Varied from	lbs.
1	{ Eminently hydraulic lime with common quartzose sand	5000 to 3000	167
2	{ Moderately hydraulic lime and quartzose sand	3000 to 2000	104
3	{ Common fat lime with quartzose sand	2000 to 1000	61
4	{ Mortar of the bridge of Valentré at Cahors, built in 1400	1893	
5	{ Mortar of the ancient theatre at Cahors	1839	
6	{ Common mortar .....	....	16
7	{ Common stone used in building .....	....	1347 to 354

On Cements exposed to the Action of Water.

(479.) Although a well-made mortar composed simply of sand and lime, if allowed to dry, becomes impervious to water so as to serve for the lining of reservoirs and aqueducts; yet if the circumstances of the building are such as to render it impracticable to preserve it from the action of the water for a sufficient length of time, the use of common mortar must be abandoned.

Cements
exposed to
the action
of water.

Among the nations of antiquity, the Romans appear to have been the only people who practised building in water to any great extent. The bay of Baiæ, like our fashionable watering-places, was the summer resort of all the wealthy of Rome, who not content with erecting their villas as near the shore as possible, were accustomed to construct moles and form small islands in the most sheltered parts of the bay, on which, for the sake of the grateful coolness of the sea, they built their summer houses and pavilions. They were enabled to build thus securely in the water by the fortunate discovery of puzzolana, which substance or some other possessing the same chemical property, is an essential ingredient in cements to give them the power of setting under water.

Before the introduction of puzzolana as an ingredient of the mortars of this Country, a substance termed *tarras* was imported from Holland for that purpose which is made use of by the Dutch, who have practised building in water to a greater extent than any other nation in Europe. It is nothing more than wacke or cellular basalt, and is procured chiefly from the Bocken-heim, Frankfort on the Maine, and Andernach, whence it is transported down the Rhine to Holland.

Various substances besides these are to be found in England, which give cements the property of setting under water; in fact, all the ferruginous clays, ochres, bluish schists, lavas, ferruginous sandstones, possess it in some degree. In the following Table are given the component parts of the substances most commonly used in this Country.

Compounds
of different
cements.

Manufactures.

Name of the substance.	Parts of silice.	Parts of alumine.	Parts of carbonate of lime.	Parts of oxide of iron and manganese.	Parts of magnesia.	Total.
Puzzolana	38	41	6	15		100 parts.
Common basalt ..	46	30	10	8	6	100
Amorphous basalt	47.5	32.5		20		100
Parker's cement ..	22	9		13	55	100 grains.
Loftus' cement ..	25.5	5		10.5	55.5	100
Mulgrave cement.	21.5	7.5		13.5	55	100

It should be here observed that the limestones which produce what we have termed hydraulic limes, contain these substances, combined with them in a small proportion, so that they will harden under water: a further addition of the above substances, however, in all cases improves their quality.

Mr. Smeaton, when engaged in the erection of Eddystone lighthouse, made a set of experiments in order to form a cement proper for that undertaking, the peculiar difficulties of which required one of the most perfect quality.

Smeaton's experiments.

(480.) The manner in which he made the experiments, was by mixing together as many of the ingredients as would form a ball of two inches diameter, which was allowed to set to such a consistence as not to yield to the pressure of the fingers, and placed in a vessel of water so as to be entirely covered; and being left there for a considerable time, he judged from the action the water had upon it how far it was calculated for his purpose.

Balls of common mortar tried in that way immediately dissolved, and those of two parts slacked lime and one of tarras would not always stand the test, but when made of equal measures of lime and tarras, they stood it very well. He tried in this way a variety of different limes mixed in various proportions with tarras, puzzolana, minion, &c., and ultimately decided upon equal parts of blue lias, lime, and puzzolana to be the most perfect composition for water cements.

In the course of his inquiries he was led to the following opinions.

That the degree of calcination of limestones was not of material importance.

That the water cements are equally good made with salt water as with fresh; or if any preference, it is in favour of the salt water. That lime made from soft limestones or chalk was equally good with that made from sand limestones. That although the practice of beating mortar well up is an advantage where common lime and a small quantity of tarras is used, yet where tarras is not spared and the lime is of superior quality, the repetition of beating appears not to be material.

That puzzolana and lime mixed with water so as to be in a perfectly fluid state, would settle to the bottom and become perfectly hard. This was important in enabling him to obtain a perfect grout for the vertical joints of the masonry.

That minion, which is a substance found very commonly with iron ore, when mixed up with equal parts of cement, is much harder than lime, but inferior to lime and puzzolana.

Mr. Smeaton has given the following Table of the proportions of the ingredients of a variety of cements, which may be used in different situations according to the facility of obtaining the materials.

Machinery.

No.	Water lime with puzzolana.	Lime powder.	Puzzolana.	Common sand.	No. of cube feet.	Expense per cube foot.
		Bls.	Bls.	Bls.		s. d.
1	Eddystone mortar	2	2	..	2.32	3 8
2	Stone mortar	2	1	1	2.68	2 11
3	Stone mortar, second sort...	2	1	2	3.57	1 7
4	Face mortar	2	1	3	4.67	1 4
5	Face mortar, second sort ...	2	0 1/2	3	4.17	1 1
6	Blacking mortar	2	0 1/4	3	4.04	0 11
	Water lime with minion.		Min.			
7	Face mortar	2	2	1	3.22	1 5 1/2
8	Face mortar, Calder compos.	2	1	2	3.57	1 1
9	Blacking mortar	2	0 1/2	3	4.17	0 10
10	Blacking mortar, second sort	2	0 1/4	3	4.04	0 9 1/2
	Common lime with tarras.		Tar.			
11	Tarras mortar	2	1	..	1.67	4 0
12	Tarras mortar increased...	2	1	1	2.50	2 0
13	Tarras mortar increased further	2	1	2	3.45	2 0 1/2
14	Tarras mortar increased still further	2	1	3	4.35	1 8
15	Tarras blacking mortar	2	0 1/2	3	3.50	1 2 1/2
16	Tarras blacking mortar, second sort	2	0 1/4	3	3.37	0 11 1/2
	Common lime with minion.		Min.			
17	Ordinary face mortar	2	2	2	2.75	1 5 1/2
18	Ordinary face mortar, 2d sort	2	1	3	4.34	0 8 1/2
19	Ordinary blacking mortar ..	2	0 1/2	3	4.05	0 8
20	Ordinary blacking mortar, second sort	2	0 1/4	3	3.92	0 7 1/2

The author makes the following observations on the preceding Table.

1. Those that would make mortar according to the preceding Table, should know, that the materials are all supposed to be in a *dry* state when measured. Smeaton's observations.

2. That the lime is supposed to be thrown into the measure with a shovel with some *degree* of force; for if put in as light as possible, in the way to make the most measure of it, there will be a want of the real quantity, and if pressed down, the measure will contain considerably more than what can be expected in *purchasing* the material; and the same may be said of the puzzolana, the tarras, and the minion.

3. Respecting sand, it is particularly to be noted, that, if in a moist state, the real quantity is considerably less under the same measure than if dry, and that in an *uncertain* degree; and as moist sand is most frequently bought for use, it is advisable that the operator should take a means of finding the difference of the proportion, and allowing accordingly in measure.

4. It should also be observed, that if the sand is not naturally a composition of *fine* and *coarse*, it should be rendered so by a mixture of different sorts; the proportion of *one* to the *other* need not be much studied.

5. The due beating of the mortar is, however, of *great* consequence; and without going into that repetition of beating, which has been always looked on as essential to the making the common tarras mortar, such as No. 11, a degree of beating sufficient to give it all *possible* consistence and substance before it is used, is in reality *indispensable*. And the method that has been found to answer the end in the most satisfactory way is to mix the due proportion of the lime and the puzzolana, the tarras, or the minion, together in dry powder; and it will also be well to have at least one-third of the *sand* (either fine or coarse) likewise dry. Put as much water in the lime, as that with a shovel or beater you can bring it to a paste of a moderate consistence, but rather more wet than to be properly used as mortar in that state; then by degrees beat in the moist

Manufac-
tures.

sand, and afterwards the dry, bringing it to a consistence by beating after every addition. The dry sand is intended to take up the superfluous moisture, so as to render the mortar immediately fit for use; and if this has not brought it to a sufficient stiffness, you may let it be till it inclines to set, and then beat it up to the due consistence; or, if immediately wanted, you may beat in a little dry lime powder to drink up the superfluous moisture; always, however, *faithfully* remembering not to terminate the beating till the mass has got *all* the toughness that you find it will acquire by beating. This method fully answers where *water lime* is concerned.

6. The customary allowance for tarras mortar beating, first and last, is a day's work of a man for every bushel of tarras; that is, for two bushels of lime powder with one bushel of tarras; so that, by No. 11, if a labourer's day's work (as at London) is rated at 2s., then, the bushel of tarras being valued at 4s., the beating will be half the price of the tarras; and the mortar produced being only $1\frac{1}{3}$ cube feet, the beating of the mortar will therefore amount to $14\frac{1}{2}d.$ per cube foot; whereas, in the way just mentioned, a man in half a day will beat to a very good consistence the whole produce that can be made, in any of the articles, from two bushels of *lime*; so that the beating of the best face mortar, as No. 4, being $4\frac{2}{3}$ cube feet, will be done for less than $2\frac{1}{4}d.$ at the same rate of labour.

Vicat on
water
cements.

(481.) M. Vicat also made a number of experiments on water cements, of which the following is an abstract.

His method of making of the experiments differed from that employed by Mr. Smeaton in the employment of conical glasses about three inches in diameter and four inches in height, which he filled with the composition instead of making it up into a ball. He ascertained the time each specimen required to harden to such a degree as to bear the weight of a polished steel rod filed square and loaded at the top, without visible impression. He also tried the comparative hardness in each specimen by observing the depth a steel rod was buried into it by a regular and constant percussion.

The following Table will give the results of his experiments on various compositions, immersed one year in water.

Lime slacked by immersion and powdered.		Granite sand.	Brick cement.	Days required for the mortars to harden so as to support a steel point loaded with a certain weight.	Relative resistance of each mortar after one year's immersion.
Common and very fat.	Middling and hydraulic.				
2.70		1.00	1.00	19	100
2.00		1.00	1.00	16	510
1.50		1.00	1.00	18	570
1.00		1.00	1.00	8	1000
0.50		1.00	1.00	9	826
2.70			2.00	8	1000
2.00			2.00	8	1500
1.50			2.00	7	2366
1.00			2.00	6	2777
0.50			2.00	6	1108
	2.70	1.00	1.00	17	390
	2.00	1.00	1.00	16	693
	1.50	1.00	1.00	12	693
	1.00	1.00	1.00	8	907
	0.50	1.00	1.00	12	615
	2.70		2.00	12	1150
	2.00		2.00	12	1200
	1.50		2.00	10	1234
	1.00		2.00	8	1384
	0.50		2.00	10	1234

By the term brick cement, we understand M. Vicat to mean calcined ferruginous clay. Machinery.

It will be seen here that within moderate limits, according to the circumstances and the nature of the materials, a due attention to their respective proportions may go so far as to affect the resistance of the mortar tenfold. In general, the influence of these proportions is the most powerful when the lime and puzzolanas or bases have the least energy of action.

The results of various other experiments by the same author may be comprised in the following statements.

With respect to the proper degree of calcination for different puzzolanas, which term he employs for the basis of all water cements:

1. That the first degree of calcination is the fittest for clay and ferruginous sandstone, and that the energy of these substances, as water cements, rapidly diminishes as they approach the state of vitrification.

2. That pit coal reduced to ashes by a slow fire is preferable to that in the state of scoriæ whether hard or friable, light or heavy.

3. That blue schist requires such a heat as will swell it.

4. That basalt should be fused.

It is particularly when these substances are combined with a common very fat lime, which of itself scarcely resists water, that efficacy as water cements is the most seen to depend on the degree of their calcination.

5. That an excess of lime in water cements retards the setting. The proportions the most favourable to speedy setting, are also those which ultimately give the greatest hardness.

6. That the most active puzzolanas combined with the common fat limes set sooner than with the hydraulic limes; but the latter with the most middling puzzolanas are the most active of all; and that the second method of slacking lime (as described in the former part of this notice) generally appears preferable to the first mode for speedy setting.

7. That water cements made with common lime make more progress in hardening from the second to the third year, than from the first to the second.

8. And that the cements made with the highly hydraulic limes have acquired nearly their utmost hardness at the end of the second year.

(482.) Mr. Brunel, previous to the commencement of the operations in the Tunnel under the Thames, made some experiments in order to ascertain the absolute strength of Roman cement in the following manner. Mr. Brunel's experiments. Pl. xxxvii. Fig. 3.

The bricks were stuck against a wall, as represented in fig. 3, plate xxxvii. on the face of each other, so that they sustained their horizontal position entirely by the strength of the cement.

1st Experiment with Francis and White's cement mixed without sand.—Thirteen bricks were sustained, the two at C were added by way of weight, then four at B, when in placing the last the arm broke at A.

2d Experiment, fig. 4.—Twelve bricks were fixed in the same manner; nine bricks were added as here represented, and left in that state without breaking. Both these experiments were made some weeks after the bricks had been fixed to the wall. The cement was therefore perfectly dry.

3d Experiment with Turner and Montague's cement.—In two hours, eleven bricks supported themselves in the manner above represented, and some weeks after twenty-one bricks were placed at the extremity, which broke it.

4th Experiment.—In two hours and ten minutes,

Manufactures.

eleven bricks supported themselves placed edgewise, and several weeks after four more were added at the extremity, which broke the arm at two bricks from the wall.

In none of these experiments has the cement broken off; it is invariably the brick, or the want of complete adhesion to the surfaces of the bricks, that has occasioned the fracture.

Other experiments were made with Weston's Roman cement. Two piers six feet long and fourteen inches square were constructed, one with pure cement, and the other with half cement and half sand. When dry they were laid transversely on props, and were supported three inches from each end and loaded in the middle. At the end of a fortnight a weight of eight hundred and ninety-six pounds was placed on each of them, which broke that built with the sand and cement in half an hour after, but the other continued to support the weight.

Mr. Brunel made some other experiments on this sub-

ject; for a description of which we refer the reader to Machinery. the third edition of Barlow's *Essay on the Strength of Timber and other Materials*.

Mr. White also has made similar experiments on the strength of mortars composed of different proportions of puzzolana, which will be found in No. XXXIX. of the *Quarterly Journal*.

Colonel Pasley and other authors, besides those whose labours we have described, have written on the subject of cement; among whom Dr. Higgin's name stands very high. We have, however, omitted to give a description of his experiments: in the first place because the proportions being made by weight instead of by measure, are apt to lead to error; and in the next because his results do not differ materially from those of Mr. Smeaton, to whose Reports we have been greatly indebted, as also to an excellent article on M. Vicat's experiments in the *Repertory of Arts*.

TABLE exhibiting the Composition of Cements that have been employed in various Public Works in England.

Date.	Name of the building.	Proportion and description of lime.	Proportion and description of sand.	Proportion and description of base.	Situation in the building.	Name of the engineer.	Remarks.
1768	Eddystone Lighthouse ...	{ 1 lias lime 1 common lime	....	1 puzzolana	{ Face work under water	Smeaton	Year 1758.
1766	Coquett dam	{ 2 slacklime 1 quicklime	1 sand and pebbles 1 sharp sand	1 minion 1 puzzolana	Backing Face work	, ,	Down-stream aisler
1827	East London Dock	{ 1 quicklime 1 1/2 Dorking lime	2 common mortar 3 common mortar	1/2 puzzolana	Face work Backing	, ,	Up-stream aisler
1827	Eastern entrance of the London Dock	{ 1 Dorking lime 1 Dorking lime	3 1/2 sand 2 1/2 river sand	1 puzzolana	Face work Backing	Palmer , ,	
1830	Tunnel under the Thames Blisworth Tunnel	1 blue lias lime 1 Southam lime	3 sharp sand 3 sand	 1 Roman cement	Face work	, , Brunel	
1830	New London Bridge	2 Haling lime	3 sand	1 puzzolana	{ Face work under and above water	Rennie	
	Staines Bridge	2 Haling lime	3 sand	1 puzzolana		Rennie	

Colour-mills.

Colour-mills.

(483.) These are made use of by painters, dyers, &c. for reducing the matters which they employ in colouring into a fit state for use. They are, of course, varied in their construction, owing to the different nature of the substances from which the colour is obtained. The colours employed by house painters, which are not required to be very fine, are ground with oil in mills with horizontal stones similar to corn-mills, or by merely passing them several times between two horizontal rollers, these being each time adjusted so as to be nearer to each other.

For artists, who require their colours ground to a very high degree of fineness, a marble slab and pebble muller are generally employed, and water is mixed with the matter while grinding instead of oil. The use of water is preferred, because it allows the colour to grind more freely, and consequently to be more readily reduced to a fine state, and at the same time combines with the dirty and impure parts of the substance, which by this means can be separated from it; but this method of grinding colours is found very injurious to the health of the workman, from the position he is obliged to stand in to work, which causes him to inhale the volatile parts of the mixtures, which are sometimes very noxious, particularly when litharge of lead is mixed with the water, a custom not unfrequent.

A mill to remedy this evil was projected by Mr. Rawlinson of Derby, who received a medal from the Society

of Arts for his invention, which consisted of a marble roller working inside a concave marble muller, which covered one-third of its circumference. By this means the paint could be brought much oftener under the muller in a given space of time, and consequently a greater quantity ground than by the usual method above described.

Fig. 3. pl. xxxvi. is an elevation of the Machine: A is a roller or cylinder, made of any kind of marble; black marble is esteemed the best, because it is the hardest, and takes the best polish. B is the concave muller, covering one-third of the roller made of the same kind of marble; it is fixed in a wooden frame *b*, which is attached to the stand or framework of the Machine at *l*; *h* is a piece of iron about an inch broad, which is used to keep the muller steady. It has a small binding screw with a fly nut at *c*, which is for the purpose of laying more pressure on the muller if required, as well as to keep it steady. D is a scraper made of a clock spring, about half an inch broad, fixed in an iron frame. It turns on pivots *d d*, so that when in use the scraper lies in an inclined direction against the roller, and at other times it is turned back out of the way.

G is a slide board, made to draw out, which catches any particles of paint that may occasionally fall from the muller; upon this board is placed the plate H, to receive the paint as it falls from the scraper. F is a drawer, used to contain currier's shavings, which are said to be the best things for cleaning paint-mills.

The colours ground by this mill require to be pre-

Rawlinson's
colour-mill.
Pl. xxxvi.
Fig. 3.

Manufac-
tures.

viously finely pulverized in a mortar; they are then applied by means of a spatula or palette-knife to the point of the roller above the scraper, and the roller is turned round by means of the winch handle G, until the colour, by passing between the revolving stone and muller, is sufficiently reduced, when the scraper D, which during the operation lies back, is inclined against the stone, and the winch handle is turned the reverse way for a few revolutions in order to scrape off the colour, which falls into the dish H.

The quantity ground at once is regulated by the state of fineness to which it is required to be ground: if it is wanted to be very fine, it must be put on in small quantities and ground for a great length of time.

When the colour is ground, it is tied up in bladders for use. Mr. Rawlinson recommends instead of drawing up the neck of the bladder close, which is the common custom, to insert a cylindrical stick, and bind the bladder close round it, which, when dry, will form a tube or pipe, through which, when the stick is withdrawn, the colour may be squeezed out as wanted, and the neck again closed by replacing the stick. This is certainly a neater and much more cleanly method than the usual one of tying the neck of the bladder close, and perforating it when any paint is wanted.

The barrel of a quill may be tied in place of the stick into the neck of the bladder, with its closed end outwards, which will keep the paint secure in travelling, and when used, the end of the quill being cut off, it may afterwards be closed by a stick.

Indigo and other vegetable colours are ground dry in a mortar made of marble, or hard stone, nicely formed and polished, by a muller or grinder, nearly in the form of a pear, in the upper part of which an iron axis is firmly fixed, which is bent in the form of a crank, to serve as a handle for turning the muller: the axis is inserted when in use into two collars, so as to revolve easily and truly in the axis of the mortar. The muller has a slit or groove made through it, almost dividing it into two parts, which is useful in collecting the colour while grinding, and bringing it continually under the muller. A circular board in two halves, with a centre hole to fit the axis, is used to lay over the mortar to prevent the dust of the colours from flying out. By means of a weight, any required pressure may be added to the revolving stone.

Preparation
of indigo.

Pl. xxxvi
Fig. 4.

(484.) The mills employed by dyers for effecting the solution of indigo with the liquid with which it is mixed are differently constructed. In this process trituration or friction is as much as possible avoided: in the first place to prevent the loss of material; and in the next the inconvenience arising from the chemical action of the substance upon which it is rubbed. Fig. 4 is the elevation of a mill very commonly employed in small dye-works, intended to be worked by a man or a boy. In this Machine, the pulverization or granulation of the indigo is effected by the pressure of a number of smooth cast iron balls, like those for cannon, which, being rolled among the indigo, press it into a paste by their weight, until it unites with the liquid by which it is to be held in solution.

A is the vessel which contains the indigo, which is of a cylindrical figure; and B is an upright spindle, upon which a wheel C C is fixed, having a convenient number of arms projecting round the vessel like the radii of a circle; and below each of these arms are attached pieces of iron, which engage the balls, and cause them to revolve with the wheel. By this means, when the

wheel C C is turned, all the balls in the vessel A are set in motion, which by rolling over the indigo gradually press it until it unites with the water or liquid with which it is surrounded. The mill is moved by a handle D, upon the axle of which is a pinion which engages the bevelled wheel E upon the vertical spindle of the rolling wheel C. F is a cross bar, with balls at the end, which serves as a fly regulator to the motion of the Machine.

When the indigo is found to be sufficiently dissolved and united with the water, the liquid thus formed is drawn off in any other vessel for use by means of a vent and spigot placed in any convenient part of the bottom of the vessel.

This Machine, although very ingenious, is not suited to works on the large scale, where much indigo is consumed. In such cases, steam power is generally employed to work the indigo-mills, and they are constructed so as to require no attendance except to empty the vessel when the indigo is sufficiently mixed, and to add a new supply. A semicircular vessel of cast iron is placed upon a strong wooden frame, having a cover made in two pieces, with a circular aperture to admit an upright shaft, which descends to the bottom of the vessel, and the upright shaft is jointed to a horizontal shaft of wood, the other end of which is connected with a crank driven by the steam engine, whereby a reciprocating or alternate motion is given to the upright shaft, which sets in motion iron cylinders in the body of the vessel, and produces the same effect in grinding and mixing the indigo as the balls in the Machine first described. The cylinders may be made of any diameter or length which is found convenient, and the greater the mass of iron they contain, the quicker and more effectually will be their operation upon the colouring matter, provided there is a sufficient power to drive them. As this Machine requires no attention whatever, it is found very useful in large dye-works, as by means of it the men can constantly command a large supply of prepared indigo, which may be drawn off when wanted. It is also advantageous, because the longer it is under the preparing process, the better in every respect: fresh indigo is of course added as the supply gets low.

(485.) Among the colour-mills employed by dyers must be included those made use of for preparing logwood, madder, and other woods, for the process of infusion, by reducing the material into very small pieces or shavings, which, of course, expose a greater number of particles to the action of the water, and by this means the dyeing property is more readily extracted from them. Mills for this purpose require considerable power, and are therefore generally worked by the steam engine. They are at the same time very simple in their construction, consisting of a horizontal shaft put in motion by Machinery, upon which a cast iron circular wheel or plate is attached so as to revolve very truly in the plane of its motion. This plate has a plane or cutter attached to it so as to project as much above the surface as it is required to have the shavings in thickness. The axle has a bearing immediately in front of the revolving plate, upon a part of the framework of the Machine; this framework has also attached to it a hollow piece of cast iron, the opening of which leads in an inclined direction to the plate, and to such a part of it that the cutter or plane passes the end of the square opening every revolution of the wheel. The log or other wood to be cut is passed down the inclined cast iron tube, and forced by the workman against the surface of the

Machinery

Preparation
of logwood.

Manufac-
tures.

Machinery

Pl. xxxvi.
Fig. 5.

revolving plate or wheel. The Machinery being thus put in gear, a shaving of the wood is taken off by each revolution of the cutter as it passes the end of the tube.

In large works, where a great quantity of logwood is required to be cut, this method does not answer so well, as an attendant is required to each log, which consumes a great deal of labour. In such cases the mills are generally so constructed that one man can attend to several logs at the same time. Fig. 5 is a plan of a mill very commonly employed in large works. A A A A is a strong wooden framework which supports a platform C C. B is the cutting barrel, which is made of wood with cutters round the circumference; it has bearings in plumber blocks attached to the framework A, and is put in motion from the Machinery by the spur wheel D. The platform is placed in an inclined position, and in such a direction with respect to the wheel that the logs meet it at an angle with the circumference. The logs are seen at L L; they are attached to a frame E E, which is moved forward by the racks and pinions R R, P P. The action of the Machine will thus be readily understood. The logs being fixed in the movable frame, and the Machinery put in motion, the attendant, by the racks and pinions, forces the end of the logs against the wheel, which by its revolution cuts off little chips or shavings, which fall into a proper vessel placed beneath to receive them.

Preparation
of woad.

(486.) Woad, which is a shrub grown in some parts of England, from which the colouring matter of the same name is obtained, undergoes several processes to prepare it for the dyer. The plant is conveyed to the mill in carts, which are so contrived as to be lifted from their axle, and raised by a crane so as to deposit their contents in the upper floor of the mill. In this floor there are holes through which the plants are passed to be conducted to the grinding wheels, which are about three feet in width, and constructed with iron bars on their circumferences, for the purpose of crushing the woad; they are fixed eccentrically on their shafts, so that their diameter is greater on one side than the other. The bruised woad is thrown into rooms on the sides of the mill, destined for its reception, by means of shovels, where it remains until the juice is so much drained off as to leave it in proper condition for being formed into balls, which is done by labourers with an apparatus for the purpose. It is laid upon trays, to be conveyed to the drying ranges, where it is kept until sufficiently dry, and then laid by until the whole crop has undergone the same operations, and the workmen are ready to manufacture it.

To prepare it for use in the Art of dyeing it is necessary it should undergo a proper degree of fermentation, which is accomplished in the course of seven or eight weeks. This is termed, in the technical language of the Art, *couching*. It is effected by regrinding the balls in the same mill as before, to a fine powder, and then spreading it upon the floors of the room in which the balls were formed, to the thickness of about three feet, where it is then moistened with water to keep it in a proper slow state of fermentation, and so managed by turning that it may pervade the whole in an equal manner. In this business the direction of an experienced workman is necessary, as, in the turning, it is of much importance that the parts of the materials be perfectly divided, which can be effected only by a nice management of the shovel. It is also stated, that much advantage has been found

in the goodness of the woad from the drying and storing being performed in a careful manner. When this attention is neglected, the woad will not, on being broken between the finger and thumb, draw out into fine hair-like filaments, or in the technical language of the manufacturer, *beaver well*. A proper attention to this particular state of the woad is necessary, as the use of this substance in the blue vat of the dyer is not merely to afford the colour of the plant, but by bringing on a very gentle fermentation to excite the indigo in the same vat to yield its colouring principle more perfectly.

When the heat in the process of couching has gone too far, the substance will be what is termed *foxy*, and when it has not proceeded to a sufficient degree, it will be what is termed *heavy*; when the material be good, it will not soil the fingers by being rubbed on them. In the conclusion of the process, the cooling is effected in so gradual a manner as to render it not liable again to ferment; and it is of course proper for being preserved in casks, or in any other way; being then ready for use.

The preparation of woad as practised in France is rather different. The plant puts forth at first five or six upright leaves, about a foot long and six inches broad. When these hang downwards they are considered fit for gathering: five crops are gathered in a year. The leaves are carried directly to mills, which are sometimes made with running stones, like an oil-mill, or with a grinder, similar to a bark-mill, and there ground into a smooth paste; but if this process were deferred for any length of time the leaves would putrefy. The paste is laid in heaps, pressed close and smooth, and the blackish crust which forms on the outside is immediately united if it happens to crack; for if this were neglected, little worms would be produced in the cracks, and the woad would lose a great part of its strength. After lying for sixteen days the heaps are opened, the crust is rubbed and mixed with the inside, and the matter formed into oval balls, which are pressed close and solid in wooden moulds. They are then dried upon hurdles: in the sun they turn black on the outside, and in a close place a yellowish colour, particularly if the weather be rainy. The dealers in the article prefer it in the former state, although it is said the workmen find no great difference between the two. Good balls are distinguished by their being weighty, of an agreeable smell, and being within, when rubbed, of a violet colour. For the use of dyers, these balls require a further preparation. They are beaten with wooden mallets on a brick or stone floor into a gross powder, which is heaped up in the middle of the room to the height of about four feet, a space being left for passing round the sides; the powder, moistened with water, ferments, grows hot, and throws out a thick fetid fume; it is then shovelled backwards and forwards and moistened every day for twelve days; after which it is stirred less frequently, without watering, and at length made into a heap for the dyer.

Astruc proposes the manufacturing of fresh woad leaves in Europe after the same manner as the indigo plant is manufactured in America, and thus preparing from it a blue fecula similar to indigo, which from his own experiments he has found to be practicable. Such a management would doubtless be accompanied with some advantages, though possibly woad so prepared might lose those qualities which now render it in a large business preferable on some accounts to indigo, as occasioning greater despatch when once the vat is ready,

Manufac-
tures.

and giving out its colour less hastily, so as to be better fitted for dyeing very light shades.
The immense extent of dyeing substances exported

and imported, and its growing increase, will be seen by Machinery the following Table.

(487.) *An Account of the Quantities of the undermentioned Colours used in Dyeing, Imported into and Exported from the United Kingdom, the Quantities cleared for Home Consumption, and the Net Produce of the Duty thereon, in each Year, commencing 5th January, from 1820 to 1831, both inclusive.*

COCHINEAL.					FUSTIC.				
Years.	Quantities.			Net Revenue.	Quantities.			Net Revenue.	
	Imported.	Exported.	Cleared for consumption.		Imported.	Exported.	Cleared for consumption.		
	lbs.	lbs.	lbs.	£.	Tons.	Tons.	Tons.	£.	
1820	160,633	56,480	66,200	7,595	2,770	1,067	2,399	2,904	
1821	116,498	48,850	79,121	9,426	2,635	556	2,646	3,294	
1822	131,737	59,095	76,982	9,593	2,548	583	2,499	2,996	
1823	394,713	55,339	77,388	9,029	5,189	174	4,085	4,967	
1824	219,343	114,964	116,437	13,953	4,766	477	4,562	5,592	
1825	304,858	92,782	126,875	9,448	5,952	707	4,790	2,532	
1826	195,165	76,911	94,426	2,753	3,679	1,056	3,537	760	
1827	320,722	145,756	171,325	4,121	4,112	506	3,845	822	
1828	258,032	158,109	147,819	3,535	7,597	718	6,656	1,420	
1829	288,456	153,738	127,954	3,014	7,365	1,464	6,006	1,210	
1830	316,589	100,059	182,217	4,390	5,112	672	5,814	1,202	
1831	224,371	168,329	134,222	3,339	6,335	249	5,767	1,171	

GUM ARABIC.					GUM SENEGAL.				
	Cwts.	Cwts.	Cwts.	£.	Cwts.	Cwts.	Cwts.	£.	
1820	9,115	146	5,663	3,391	6,233	351	9,865	5,806	
1821	15,265	223	8,510	4,927	11,230	143	7,916	4,712	
1822	10,434	150	8,343	4,966	3,099	382	5,971	3,379	
1823	19,424	188	12,662	7,538	3,169	6	2,854	1,703	
1824	25,140	387	12,556	7,213	11,462	90	9,638	5,767	
1825	23,452	5,714	9,643	5,581	13,137	330	6,137	3,640	
1826	18,974	6,291	7,473	4,458	1,802	259	4,970	2,982	
1827	11,695	2,582	15,209	9,075	2,279	12	7,669	4,601	
1828	5,211	1,507	18,167	9,599	12,516	51	9,530	5,530	
1829	8,233	2,049	17,250	7,701	7,948	4	8,539	3,468	
1830	7,785	1,070	14,002	6,375	9,779	302	11,203	4,458	
1831	7,285	280	9,470	3,951	11,831	1,081	10,111	6,075	

GUM ANIMI AND COPAL.					GUM TRAGACANTH.				
	lbs.	lbs.	lbs.	£.	lbs.	lbs.	lbs.	£.	
1820	340,980	193,369	40,842	3,429	8,341	12,023	8,935	451	
1821	223,339	121,514	38,878	3,204	23,970	2,921	11,642	602	
1822	163,491	101,272	66,682	5,556	25,380	8,925	18,114	906	
1823	261,220	96,110	117,791	5,254	6,865	336	11,780	599	
1824	438,777	258,414	146,343	2,473	24,757	1,847	20,736	1,045	
1825	266,476	210,729	138,494	3,367	33,956	2,363	27,932	1,420	
1826	133,442	113,652	79,654	1,896	27,196	201	10,348	520	
1827	186,609	86,670	123,574	2,951	6,682	919	21,030	1,056	
1828	186,957	50,158	123,859	2,943	24,473	613	24,823	1,243	
1829	251,297	123,479	129,724	3,095	30,908	2,197	24,536	1,225	
1830	82,837	24,712	127,070	3,054	26,449	599	28,165	1,410	
1831	223,576	52,423	116,376	2,800	50,442	2,711	38,300	1,921	

TABLE continued.

Manufac-
tures.

Machinery.

INDIGO.					LAC DYE.				
Years.	Quantities.			Net Revenue.	Quantities.			Net Revenue.	
	Imported.	Exported.	Cleared for consumption.		Imported.	Exported.	Cleared for consumption.		
	lbs.	lbs.	lbs.	£.	lbs.	lbs.	lbs.	£.	
1820	5,089,292	4,379,369	2,393,158	40,759	424,101	43,350	237,855	5,830	
1821	4,063,109	2,986,116	2,059,495	35,805	641,449	80,862	317,724	7,936	
1822	2,923,514	2,378,948	2,091,729	40,798	872,967	29,578	349,367	8,734	
1823	7,229,150	2,783,504	2,483,495	48,941	528,669	13,045	414,935	9,276	
1824	5,080,972	2,795,790	2,468,911	51,347	598,258	52,493	481,847	7,324	
1825	6,793,631	3,870,929	2,386,724	43,987	539,393	61,089	368,465	4,624	
1826	8,085,751	4,366,426	1,901,696	24,411	760,729	68,603	395,609	2,775	
1827	6,067,747	3,085,465	2,396,490	31,379	728,730	65,902	456,637	3,132	
1828	9,913,010	4,588,658	3,064,915	39,367	694,148	48,176	430,665	2,412	
1829	6,748,281	4,286,605	2,113,830	28,169	594,494	26,763	462,988	2,340	
1830	8,216,440	4,686,748	2,676,945	34,262	488,050	73,773	578,061	2,420	
1831	7,307,313	4,374,241	2,490,134	34,782	782,399	143,611	454,779	1,518	
LOGWOOD.					MADDER.				
	Tons.	Tons.	Tons.	£.	Cwts.	Cwts.	Cwts.	£.	
1820	5,292	5,552	4,347	2,041	60,831	2	60,375	35,909	
1821	8,809	4,749	5,078	2,285	55,336	1	48,466	27,328	
1822	17,236	5,469	9,000	4,130	91,735	86	84,232	46,479	
1823	15,429	8,734	8,764	4,016	81,341	77	76,456	38,577	
1824	19,105	5,967	11,034	5,045	63,174	234	60,064	35,954	
1825	22,106	6,848	12,384	3,147	90,487	147	72,255	29,750	
1826	10,246	5,894	6,807	1,317	40,172	333	49,457	14,988	
1827	10,887	7,177	7,162	1,441	76,009	229	86,739	26,137	
1828	14,046	6,395	9,297	1,926	96,064	..	95,652	28,976	
1829	13,893	6,227	8,852	1,769	70,017	380	69,658	21,223	
1830	16,782	5,938	10,100	1,995	51,624	200	49,205	14,903	
1831	14,853	6,011	10,405	2,113	43,935	280	48,756	14,615	
MADDER ROOTS.					NICARAGUA WOOD.				
	Cwts.	Cwts.	Cwts.	£.	Tons.	Tons.	Tons.	£.	
1820	20,378	74	19,737	4,909	247	306	809	1,094	
1821	53,907	25	44,309	10,960	267	154	472	588	
1822	43,580	7	48,584	12,119	1,646	351	1,428	1,869	
1823	38,585	..	40,500	10,102	1,994	591	1,420	1,831	
1824	74,445	..	69,285	17,205	3,558	868	2,115	2,731	
1825	46,271	..	36,830	5,620	4,853	474	2,730	2,777	
1826	36,424	..	40,376	3,000	3,439	748	1,774	1,328	
1827	41,370	16	49,177	3,680	3,060	1,129	1,911	1,433	
1828	66,925	113	67,243	5,049	1,149	1,028	1,127	845	
1829	33,541	267	39,805	2,982	1,839	765	856	642	
1830	37,074	150	35,886	2,710	1,089	367	1,460	1,095	
1831	52,449	119	53,862	4,044	1,277	200	1,485	1,116	
QUERCITRON BARK.					SAFFLOWER.				
	Cwts.	Cwts.	Cwts.	£.	Cwts.	Cwts.	Cwts.	£.	
1820	10,446	5,003	7,647	755	863	28	1,059	463	
1821	31,961	7,505	20,278	1,055	2,338	212	1,860	809	
1822	28,814	10,243	18,054	1,701	4,466	466	3,073	1,344	
1823	21,598	4,241	18,457	1,717	8,908	832	4,137	1,808	
1824	35,332	3,842	28,801	2,877	7,984	377	5,699	2,486	
1825	30,800	4,086	25,761	2,567	7,222	356	4,517	1,542	
1826	12,280	1,979	15,546	942	6,468	693	2,338	374	
1827	11,392	2,135	14,264	713	2,524	1,623	3,172	469	
1828	24,566	2,174	23,815	1,191	2,162	1,973	5,649	726	
1829	28,304	2,785	22,821	1,141	4,624	1,316	4,371	547	
1830	36,981	6,678	27,712	1,397	2,627	1,554	3,284	419	
1831	26,458	4,407	24,512	1,223	2,772	934	2,300	289	

Manufactures.

TABLE continued.

Machinery.

SHUMAC.					SMALTS.				
Years.	Quantities.			Net Revenue.	Quantities.			Net Revenue.	
	Imported.	Exported.	Cleared for consumption.		Imported.	Exported.	Cleared for consumption.		
	Cwts.	Cwts.	Cwts.	£.	lbs.	lbs.	lbs.	£.	
1820	68,808	3,147	66,415	5,104	629,873	121,199	393,467	17,119	
1821	108,991	676	103,323	8,057	476,771	126,366	427,683	16,929	
1822	55,869	2,858	57,245	4,362	687,366	55,735	559,828	22,149	
1823	101,707	941	96,656	7,360	490,494	108,177	424,660	16,809	
1824	129,960	3,054	118,554	8,914	399,308	45,190	430,316	16,957	
1825	102,182	1,776	98,909	5,929	544,408	82,990	397,821	15,747	
1826	51,022	1,741	58,538	2,719	215,691	16,750	332,147	11,867	
1827	81,103	2,189	76,646	3,516	521,173	5,586	400,239	12,518	
1828	95,935	169	100,344	4,832	496,160	3,951	554,092	13,802	
1829	80,191	2,213	78,874	3,792	376,675	2,913	353,468	8,832	
1830	112,477	746	107,453	5,276	444,428	13,858	372,516	9,312	
1831	133,800	2,076	127,822	6,259	391,523	4,905	348,115	8,669	
VALONIA.					YELLOW BERRIES.				
	Cwts.	Cwts.	Cwts.	£.	Cwts.	Cwts.	Cwts.	£.	
1820	48,522	131	49,656	6,109	1,784	37	2,779	3,959	
1821	10,176	100	16,879	2,181	3,436	575	2,265	3,217	
1822	33,227	1	34,412	4,183	1,218	92	2,329	3,318	
1823	88,980	12	81,177	10,036	1,346	3	2,035	2,895	
1824	158,483	150	152,981	19,068	1,568	..	1,876	2,668	
1825	60,349	10	60,638	5,458	3,648	52	2,959	3,507	
1826	56,736	..	59,606	4,470	2,836	228	1,729	1,204	
1827	98,743	..	94,489	7,058	2,626	33	3,408	2,386	
1828	165,526	57	165,309	12,277	2,278	45	1,792	1,254	
1829	111,390	43	110,773	8,203	1,516	26	1,813	1,269	
1830	150,129	26	154,155	11,376	2,970	66	2,319	1,609	
1831	134,307	34	137,194	10,264	3,425	303	1,685	1,180	
ZAFFRES.									
	lbs.	lbs.	lbs.	£.					
1820	83,058	933	79,459	1,028					
1821	112,070	233	121,360	1,446					
1822	86,934	224	83,209	947					
1823	280,418	342	281,516	1,087					
1824	108,409	..	110,699	149					
1825	321,842	440	321,058	1,338					
1826	82,237	256	69,470	289					
1827	224,247	448	237,633	860					
1828	447,434	224	446,329	990					
1829	158,026	335	157,085	1,655					
1830	191,229	763	191,144	797					
1831	227,512	115	227,982	950					

Corn or flour-mills.

History of corn-mills.

(488.) The history of the invention of grinding corn is nearly the same as the history of mills, these having been for many Ages devoted to this one single purpose; but in the early states of Society the mill employed in this duty, if indeed such means as were had recourse to for grinding at that time deserve the name of mills, were of the most simple kind. Arthur Aikin, Esq., Secretary to the Society for the Encouragement of Arts and Science, has been at great pains in collecting from different sources historical facts relative to the form and opera-

tion of the most ancient kind of mills, and we are much indebted to him for obligingly supplying many of the following particulars. The Ancients prepared their corn for grinding, by first exposing it to a degree of heat sufficient to render it brittle, and in part to separate the husk from the grain. It was then placed in mortars and rubbed gently with a pestle, sufficiently to separate the husk, but not enough to bruise the grain, which, without some care, would have been done, the corn having been already made brittle by scorching. Such, according to Pliny, was the method practised by the ancient Romans, particularly in those grains whose husk adhered too firmly to the seed, to be removed by simple rubbing. The same mills which thus served to decorticate their barley, answered also for reducing it and their other grains to powder or flour, especially as they had been rendered brittle by toasting; but corn which has been toasted is not afterwards susceptible of fermentation, and therefore so long as the Romans adhered to this mode of preparing their grain, which was introduced by Numa, (and represented by him as a kind of religious duty,) it was impossible that they should have any other bread than mere cakes or biscuits of baked dough.

Both mortars and pestles were at first made of wood, no doubt the hardest and most compact that could be found; this material was afterwards superseded by stone, and the Etrurians seem to have given the mortar a

Manufac-
tures.

deeper and more cylindrical form than usual; they likewise furrowed the sides with longitudinal scores, and cut the bottom into rays like a star; that part of the pestle which entered the mortar was rough, and was terminated by an iron spike, intended, probably, to be placed in a hole in the centre of the star just mentioned; the pestle was worked in an upright position, and seemingly by a rotary movement on its axis. This mortar, or mill, as it may without much impropriety be called, was intended, however, only to husk the grain, not to reduce it to powder.

Roman
hand-mills.

If the corn-mill generally used in Italy, in the later times of the Roman Republic, and during the reign of the first Emperors, were of the same form as those which have been found at Pompeii, it is evident that the Italian corn-mill differed entirely from that used in Greece and in Asia, being in principle nothing more than the Etrurian mortar reversed. It consists of a stone post (the pestle) fixed in the ground, and terminated by a cone having its point cut off; a hollow cone, (the mortar,) also with its point cut off, is laid upon the solid one, and the sides of the former being somewhat less sloped than that of the latter, it is manifest that they will touch only by their lower edge, and from that part will diverge upwards, leaving an angular space between them, the width of which will be regulated by the difference of slope in the exterior and interior cones: this space will be the grinding surface. To the upper part of the outer cone is fixed a funnel-shaped hopper, and two opposite horizontal beams also project from it, to which are attached the animals by whose strength the mill is turned. The corn being delivered from the hopper into the space between the two cones, is there ground by the rotation of the outer one, and the meal drops out at the bottom where the edges of the cone come in contact. At first the labour of slaves in general was employed to work these mills, but it was afterwards specially imposed as a punishment on refractory ones; next, asses, cattle, or horses were used, generally the first-named, the size of the mills not requiring the work of two horses, and being more conveniently wrought by two animals than by one. The discontinuance of the use of slaves in mills is stated to have occurred about the end of the IIIrd Century, in the reign of Theodosius; this however, in all probability, applies only to public slaves. It does not appear that hand-mills, on this or any other construction, were in use among the Romans. The material of the mills found at Pompeii is a black cellular lava, such as is used at present for the same purpose in that part of Italy; but other stones, both harder and softer than this, were also employed.

Hand-mills originated in the East, at a period preceding that of the earliest historical records. Three measures of fine meal kneaded and made into cakes on the hearth form part of the hospitality of the Patriarch Abraham. (*Gen. xviii. 6.*) Mills, therefore, for grinding corn were already in use; and that these were hand-mills, we may be assured, because the Jewish people seem never to have employed any other kind, and because, even to the present day, the Arabians and inhabitants of Syria, though not entirely without cattle-mills and water-mills, in some of their largest towns, seem generally to retain the old custom of grinding their corn at home, and thus making it a regular daily domestic occupation. Working at these hand-mills has for the most part fallen to the lot of the women; and, as it is both irksome and laborious, it devolves of course to

the slaves, but only to the lowest classes of them in opulent families. It was quite accordant with the simplicity of ancient times, that the wife of the Patriarch, a man rich in servants and in cattle, should herself prepare the bread for his guests, but it would have been quite out of character to demand from her the servile labour of grinding at the mill. In ancient Egypt, the same kind of hand-mill seems to have been used, and was worked also by the lowest class of female slaves. So exclusively was this labour appropriated to them that, in order to comprehend every rank of the Egyptian people, we find the Historian making use of the expression, "from Pharaoh, that sitteth on his throne, to the maid servant that is behind the mill." And the Jewish Prophets employ the same figure as testifying the lowest state of degradation: "Virgin daughters of Babylon, thou shalt no longer be called tender and delicate, but shall sit in the dust, take the mill-stones and grind meal." Criminals and public slaves, when treated the most harshly, were condemned to the mill; thus, Samson, when made captive, and blinded and fettered, was set to grind in the prison-house. Generally one, but sometimes two persons were employed at each mill, which consisted essentially of two flat stones, the lower one the hardest and probably also the heaviest.

In many respects, the customs of the Oriental people seem to have undergone hardly any change; and modern travellers inform us, that hand-mills are still in use very generally, and of a form and construction differing in no respect (as far as we can judge) from the ancient ones. Dr. Shaw, in his *Travels in Barbary*, says, "Most families grind their own wheat and barley at home, having two portable millstones for the purpose; the uppermost whereof is turned round by a small handle of wood or iron, that is placed in the rim. When this stone is large, or expedition is required, then a second person is called in to assist; and it is usual for the women alone to be concerned in this employment, who seat themselves opposite to each other with the millstones between them."

The observations of Sir J. Chardin are to the same purpose. "In the East," says he, "they grind their corn at break of day, and when one goes out in a morning, one hears every where the noise of the mill. The employment is extremely laborious, and esteemed the lowest in the house, about which they set their black servants only, and such as are the least fit for any thing else." Hand-mills of precisely the same form and construction are at present used in India; a specimen of which is deposited in the East India Museum.

Greece received its earliest civilization from Asia and Egypt; and the tradition which preceded the Poetical History of that Country, alludes to the first introduction of agriculture, and to the substitution of corn for acorns and other wild productions of the forest. Bread and flour are frequently mentioned by Homer, the earliest of their extant writers, and, consequently, imply the existence of corn-mills. If we were entirely destitute of any account of the mill used in those times, we should yet be justified in supposing it to be the same as that in use in the Countries from which the Greeks derived their knowledge of corn: but what, in such circumstances, would only be a very probable conjecture, is reduced to matter of fact by two passages in the *Odyssey*; a Poem at once delightful from its narrative, and invaluable as a record of domestic life in what may be termed the semi-Heroic Age of Greece. The female servants of the Chief of Phæacia are represented as fifty in number, some of whom are

Machinery.

Oriental
hand-mil.

Manufac-
tures.

employed in turning the corn-mills. The mills also of Ulysses himself were twelve in number, turned by as many female slaves, grinding wheat and barley with great labour.

A hand-mill also, of the same form as the Oriental one, was for many centuries employed in the British Islands. It was called a Quern, and may possibly have been introduced by the Phœnicians, or by those Tribes, whoever they were, who first brought into the Country the Arts of Agriculture. Its use in the Western Islands of Scotland has been obsolete for hardly more than fifty years. It was worked by one or two women, as represented by Mr. Pennant in his *Tour in Scotland*. Shakspeare speaks of "labouring in the quern;" and Hakluyt, in his *History of Voyages and Travels*, mentions the use of the quern on shipboard, for grinding mustard seed. It was therefore no doubt made of various sizes, according to the use for which it was intended, and evidently was not entirely discontinued in England so late as the reign of Queen Elizabeth.

Invention
of water-
mills.

It is not known to whom the invention of water-mills is owing. Strabo, in an obscure passage, seems to speak of one set up by Mithridates. There is, however, satisfactory evidence that a corn-mill driven by water was set up at Rome soon after the conquest of Mithridates by Pompey.

The novelty of the invention, and the anticipation of the benefits to humanity likely to result from its adoption, are expressed in a beautiful copy of verses by Antipater, a Greek Poet and contemporary, of which the following is a translation.

"Cease your work, ye maidens who laboured in the mill; sleep now and let the birds sing to the ruddy morning; for Ceres has commanded the Water Nymphs to perform your task. Obedient to her call, they throw themselves on the wheel, force round the axle, and thus turn the heavy millstone." A more scientific account of the Machine is to be found in the *Architecture of Vitruvius*, who probably lived in the reign of Augustus. From this Work we learn that the mill, that is the running stone, was supported on the end of an upright shaft which served also as the axis of a flat toothed wheel; this latter wheel worked in another fixed in the upper end of the great axis, to the lower end of which the water wheel was fixed. This latter, therefore, was horizontal or nearly so, and was turned round by the force of the stream in which it was immersed. As the Machinery of water-mills for grinding corn became improved, hand-mills, though not entirely abandoned, fell into great disuse. This, however, was occasioned not merely by the greater cheapness and expedition with which the former did their work, but also by certain rights and obligations imposed by the Feudal System on Lords of the Manor. The Lord was obliged to be at the expense of erecting a mill worked by water or wind for the use of his tenants; and they, in return, were obliged to take their corn to be ground at the Lord's mill, paying him a certain toll for the convenience.

Thus the interest of the Lord, or at least of the miller whom he employed, was directly concerned in discouraging the use of private mills, and in removing one of the strongest motives to excuses for domestic slavery.

Of wind-
mills.

The wind-mill, which is undoubtedly a much more recent invention than the water-mill, came afterwards into very common use; but both the date of its invention, and even the Country in which it was first employed, are uncertain.

Steam Flour-mills.

Machinery

Steam
flour-mills.

(489.) In the year 1783, the power of steam was first applied to the grinding of corn at the Albion Mills, erected at the Southwark foot of Blackfriars bridge. This erection was most unjustly calumniated in its day, under an idea that it was a monopoly injurious to the Public; a very erroneous notion, as it was the means of considerably reducing the price of flour while it continued at work. It was destroyed by fire in 1791; an occurrence which has been with great reason imputed to design. Since that time, however, a great many steam-mills have been erected for this purpose, being found to possess an advantage over wind-mills from their perfect regularity of motion; and in Countries where coal is cheap, they can even compete with them in point of expense. The operation of grinding, by whatever power, is now performed by two horizontal stones placed at a short distance one above the other; the lower being immovable, while the upper one turns upon a spindle, and has a hole in its centre through which the corn is admitted.

The opposed surfaces of the two stones which act to grind the corn are generally perfectly plane, although sometimes each is made slightly conical, the upper one which is hollow being made rather more concave, the lower one is convex, so that they come nearer together towards their circumference; by this means it is supposed the corn has a better opportunity to insinuate itself between them generally as far as two-thirds of the radius where the process of grinding begins to take place. In stones of six-feet diameter, when formed on this principle, the upper stone is made concave about one inch at its centre, and the lower one convex about three-quarters or five-eighths of an inch; but in smaller ones of from four to four feet six inches diameter, where the velocity or number of revolutions is greater, a much less hollowing is necessary; and in these cases, the lower stone is made perfectly plane, as, by reason of the greater centrifugal force, the corn has sufficient tendency to pass from the centre to the circumference of the stones without any fall being given.

When the corn has arrived at the point where the grinding begins to take place, it passes into furrows or channels cut into the upper and lower stone, made to cross each other after the manner of a pair of scissors, (as will be more particularly described below,) and being thus reduced to powder, it passes along the furrows to the circumference, where it is received into the hopper and passed from thence into sacks or into the dressing Machine, where the coarse and fine parts are separated for sale or domestic purpose.

(490.) In plate xxxviii. we have given a section of one of the wings of the flour-mill lately erected by Messrs. George and John Rennie, in the Royal William Victualing-yard, Plymouth, from which the general action of a flour-mill will be understood; we shall afterwards describe the various parts of the mill separately. This is one of the largest and most complete mills in England, and was only completed during the last year 1833. The building which contains it is nearly 240 feet in length, and above 70 feet in height. Each wing contains twelve pair of stones driven by a 45-horse power engine situated in the body or centre of the building. The stones are 4 feet 3 inches in diameter and make 123 revolutions per minute; each pair grinding about five bushels of corn in an hour, or, which is nearly the same,

Pl. xxxviii.
Description
of the steam
flour-mill in
his Majesty's
Victual
ling-yard,
Plymouth.

Manufac-
tures.

the mill when at full work will grind upwards of 120 bushels in an hour by two 45-horse power engines, and at the same time work eight dressing Machines, and four screening or cleaning Machines for preparing the flour to be ground. The fly wheel of the engine which works the stones and dressing Machines in the right wing of the mill, is seen at *f* in the figure. *A A* is the main shaft of the engine, which has its bearings in plumber blocks bolted to the cast iron frames *a a*. It has attached to it two bevelled wheels *B B*, eight feet in diameter, which engage two smaller ones, of five feet four inches diameter, situated on the main vertical shafts *C C*, *C C*. The vertical shafts have bearings at the lower end in the cast iron frame *a a*, and in various parts of their length in plumber blocks or brasses attached to the floor of the mill. Their shafts are situated in the centre of a circular mass of brickwork *h h*, termed the hursts, which form the foundation of a strong cast iron framework *b b*, which supports the millstones and affords bearing to the Machinery employed to put them in motion. *D D*, *D D* are cog wheels of ten feet diameter attached to the vertical shaft *C C*, round the circumference of each of which are situated, at equal distances, six toothed wheels of small diameter, upon the spindles of the upper millstones, and which of course put them into very rapid motion.

The corn to be ground is deposited in the upper floor *E E*, in bins situated between the cast iron pillars *F F F*, and from which it is conducted by spouts to the screening Machines *S S*; the purpose of these is to separate the sand and other extraneous matter which unavoidably becomes mixed with the corn. They consist of a cylindrical sieve divided so as to resemble an Archimedes' screw, so that the corn being admitted at one end has, by the revolution of the cylinder, to pass over a great surface of wire, which takes from it the greater portion of the sand and dirt: when it arrives at the end of the Machine it falls into a hopper *h*, from which it is conducted by spouts *c c* to the millstones. One of these screening Machines will supply sufficient corn for six pair of stones. The hopper *h* will be observed to have two screening Machines, the object of which is, that the corn may be taken more conveniently from any part of the floor above. *d, d, d* are small hoppers supported by a wooden framing attached to the casing *m m* of the millstones, into which the corn is received immediately from the hoppers *h, h'*; *e, e, e* are spouts placed nearly in a horizontal position, which conduct the corn from the small hoppers to the eye of the millstone. They are attached to the hopper so as to admit of a slight horizontal motion, which is effected by a projected part of the axle or spindle of the stone termed the *damsel*. It is shaped like a cross, so that, by the revolution of the millstone, it keeps tapping the end of the spout *e* and gives a rapid vibratory motion to it, which causes a gradual and regular supply of corn to pass down to the stones. The flour or meal which comes from the millstones is conducted by spouts to the bins *G G*, situated on the ground-floor.

One of the main vertical shafts *C C* is continued up to the roof of the mill, in order to give motion to the sack tackle or Machinery by which the corn, after being ground, is elevated to the upper floor, to be passed through the dressing and bolting Machines, situated on the second floor, by which process the fine and coarse parts of the flour are separated from each other.

The sack tackle is very simple, and will be readily

understood from the drawing. It consists of a barrel *h*, Machinery situated on a horizontal shaft having bearings on the two beams of the roof; it receives motion when required by a system of wheelwork communicating with the bevelled wheel *g* on the vertical shaft. A rope is wound round the barrel and proceeds to the bottom of the mill, by which a sack of flour may be readily raised to any floor of the mill by merely putting the wheelwork in gear.

The dressing Machines and bolting-mills are situated at *G H*, on the second floor of the mill. The drawing being on so small a scale, we have not attempted to show any more than the box or casing by which they are surrounded to prevent the escape of the flour; but their construction does not differ from that of the common dressing and bolting Machines, which will be described in a subsequent part of this article. They are put in motion by a bevelled wheel situated on a horizontal shaft, running at right angles to the shaft *c c*, which can be put in gear with either of the bevelled wheels *w w* on the vertical shaft, in order that motion may be given to the Machines in either direction. The flour, after being divided by the dressing Machines into the different degrees of fineness required for the different purposes of the Navy, is conveyed by spouts to the lower floor, where it is received into sacks.

The floors are constructed in this mill of wood, and supported by cast iron pillars, but in the Deptford mill which has been since erected, Messrs. G. and J. Rennie have preferred the use of cast iron both in the floors and in the roof; which has not only the great advantage of superior durability, but that of rendering the mill perfectly secure against fire, an accident to which flour-mills are very liable.

We add here the following experiments showing the actual duty performed by his Majesty's mills at Gosport, Plymouth, and Deptford, which have been kindly supplied us by George Rennie, Esq.

(491.) *His Majesty's Royal Clarence Victualling-yard at Gosport, December 21, 1830.*

Experiment 1.—The steam engine equal to the nominal power of 45 horses, made by Messrs. Boulton and Watt, Soho. When the steam engine was set to work it was driving 8 pairs of millstones, each 4 feet diameter. One wire dressing Machine, dressing biscuit meal at the rate of 13 sacks per hour. One sack tackle at the end of the granary delivering a cargo of wheat to the top floor at the rate of about 120 sacks per hour, with the wheat screens and other Machinery necessary to perform the regular service of the mill. The produce of each of the 8 pairs of millstones was taken for 5 minutes. Also every other pair was taken for the same time, making the exact average rate of one pair for one hour produce 250 pounds, the wheat weighing 60 pounds per bushel; by adding one pound for evaporation in each bushel, this will be 254 pounds, making the average rate of grinding for each pair of millstones to be 4.23 bushels per hour, and the proportion of one bushel of coals to 6.52 of wheat; the coals were bad, name unknown.

Experiment 2.—One single wire Machine as under, dressed in the space of 9 minutes,

Biscuit meal	516 pounds
Pollards	26
Bran	70

Total 612

Experi-
ments on
his Majes-
ty's flour-
mills at
Gosport.

Manufac-
tures.

being at the rate of 12.3 sacks per hour; the whole being the produce of 69 bushels, or 8 quarters 5 bushels of wheat.

Llangennech coal was used; and in the space of $3\frac{1}{2}$ hours, 12 hundred weight, or 1344 pounds, or 18.16 bushels, or nearly at the rate of 5.2 bushels per hour, were consumed.

December 22, 1830.

Experiment 3.—At 20 minutes after 1 set the engine to work, supplied with coals from Lamb's Main, weighing 74 pounds per bushel, of indifferent quality. Driving 10 pairs of millstones. One wire dressing Machine with the screens, sack tackles, and other Machinery for the usual service of the mill. After working for the space of 2 hours and 42 minutes, the engine was found to have consumed 13 hundred weight, or 19.67 bushels of coals. Ground 70 hundred weight, or 132.84 bushels of wheat and dressing its production; this being the proportion of 6.76 bushels of wheat ground and dressed with 1 bushel of Lamb's Main coal. The dressing mill worked $1\frac{1}{2}$ hours.

December 23.

Experiment 4.—At 11 minutes past 8 A.M. set the engine to work, driving 10 pairs of millstones, the baking Machinery, wheat screens, sack tackle, and other Machinery necessary for the usual service of the mill. After working 3 hours there had been consumed 11 hundred weight 1 quarter 10 pounds, or 17.16 bushels of Llangennech coal, weighing 74 pounds each, in grinding 76 hundred weight 1 quarter 10 pounds, or 142.5 bushels of wheat; this being in proportion of 8.3 bushels of Llangennech coal, or $4\frac{1}{2}$ bushels of wheat per hour, for each pair of the millstones employed.

December 23.

Experiment 5.—Set the engine to work at 11 minutes past 11, driving 10 pairs of millstones, the baking Machinery, two sack tackles delivering a cargo of wheat, with other Machinery for the usual service of the mill. After working 3 hours, the engine had consumed 12 hundred weight 2 quarters 15 pounds of Durham coal, or 18.86 bushels, each weighing 75 pounds, and had ground 140 bushels of wheat, which is in proportion of 7.42 bushels of wheat to 1 bushel of Durham coal; and an average of 4.66 bushels of wheat per hour for each pair of millstones.

Royal William Victualling-yard, Plymouth, Monday, April 14, 1834.

At Ply-
mouth.

Two steam engines of 45 horse power, Boulton and Watt, diameter of millstones 4 feet 3 inches, make 120 revolutions per minute. Started the steam engine next the Basin at 22 minutes to 11, barometer 28. First, in order to clean sufficient wheat for the hoppers; this occupied half an hour. Started again at 25 minutes past 11. Engine made 19 strokes per minute. All the 12 pair only ground in 1 hour 11 bushels! but, thinking this to be a mistake, tried another trough, and found it to be 9 bushels per hour, or 108 bushels per hour for the 12 pair, or 1080 bushels in 10 hours. Stopped the engine at 3 P. M. and put on leathers.

Experiment on Western Mill, April 14, 1834. First Machinery.
Day from three to four o'clock.

First Hurst next to Basin.	Hurst next Engine.
Bushels.	Bushels.
1.....12 $\frac{1}{2}$	1.....13 $\frac{1}{2}$
2.....9 $\frac{1}{2}$	2.....9 $\frac{1}{2}$
3.....8 $\frac{1}{2}$	3.....7 $\frac{1}{2}$
4.....11 $\frac{1}{2}$	4.....11 $\frac{1}{2}$
5.....10 $\frac{1}{2}$	5.....9 $\frac{1}{2}$
6.....10 $\frac{1}{2}$	6.....11 $\frac{1}{2}$
Total 62 $\frac{1}{2}$	Total 62 $\frac{1}{2}$

Coals consumed during the above grinding of 1 hour.....7 bushels.

Result of 9 hours' work of the Western Mill. Steam engine worked from 2 minutes past 8 to 25 minutes past 5, making stoppages 25 minutes during the whole time; 19 to 20 strokes per minute; barometer 28 $\frac{1}{2}$. Coals consumed, including getting up steam, 79 $\frac{1}{2}$ bushels. Mill working 10 pairs of stones 9 hours, produced of kiln-dried wheat:

First Hurst.	Second Hurst.
Bushels.	Bushels.
1. Mayes.....110 $\frac{1}{2}$	1. Mayes...119
2. Hurwood...81 $\frac{1}{2}$	2. Up.
3. Out of work.	3. Corcoran. 97 $\frac{1}{2}$
4. Mayes.....107	4. Mayes...116
5. Ditto.....110	5. Hurwood. 95
6. Corcoran...101	6. Mayes...114
5/510	5/541
9/102	9/108 $\frac{1}{2}$
Per hour 11 $\frac{1}{4}$ = $\frac{1}{3}$	Per hour 12

Wednesday April 16, 1834.

Began to work East Mill at 20 minutes to 11, by Mr. Rennie's watch, and 21 minutes past 11 by Mr. Turnbull's.

Result of Eastern Mill.

Steam engine worked badly, made only 16 strokes.

Ground Hurst next engine house.	East Hurst.
Bushels.	Bushels.
1. Mayes.....14	1. Mayes....10 $\frac{1}{2}$
2. Ditto.....12	2. Ditto....12
3. Hurwood...10 $\frac{1}{2}$	3. Corcoran..12 $\frac{1}{2}$
4. Up.	4. Up.
5. Corcoran....10 $\frac{1}{2}$	5. Hurwood..12
6. Mayes.....11	6. Up.....9 $\frac{1}{2}$
57 $\frac{1}{2}$	57

Second Trial of Eastern Mill with Eight Pairs of Stones only

Hurst next Engine.	East Hurst away from Engine.
Bushels.	Bushels.
1. Mayes.....16 $\frac{1}{2}$	1. Mayes....14 $\frac{1}{2}$
2. Ditto.....13 $\frac{1}{2}$	2. Ditto....16
3. Hurwood....12 $\frac{1}{2}$	3. Corcoran..15 $\frac{1}{2}$
4. Up.	4. Up.
5. Corcoran....13 $\frac{1}{2}$	5. Hurwood..13
6. Up.	6. Up
55 $\frac{1}{2}$	57 $\frac{1}{2}$

Royal Victualling-yard, Deptford.

Two engines of 40-horse power, diameter of stones 4 feet, make 123 revolutions per minute. At Deptford.

Manufac-
tures.

Eight pairs of stones produced in 9 hours, from 38 quarters of wheat weighing 60 pounds to the bushel, 70 sacks of fine flour and 3 of biscuit meal, each sack weighing 283 pounds.

Prepara-
tion of the
corn.

(491.) *Preparation of the corn for grinding.*—In the most improved mills, the corn, previously to being passed through the stones, is cleaned of the dust and other refuse which is found more or less combined with it. In the mill above described, the means employed consist in passing the corn through a cylindrical sieve, which is partitioned inside so as to resemble an Archimedes' screw, by means of which the corn is made to pass over a great surface of wire before it arrives at the extremity, and the greater portion of the dust and other extraneous matter are thereby separated from it. It is then received into a hopper which conveys it to the millstones.

Sometimes mills are constructed, termed *sheeling* mills, whose only purpose is that of preparing corn for the flour-mill; the cleansing is in these mills produced by two or three processes. The corn is received from the hopper upon an inclined sieve, to which is given a reciprocating motion from the Machinery; this serves to deprive it of the sand and small seed which falls through the wires of the sieve during its passage down. It is then passed through a pair of millstones, by the circular motion of which it is sheeled, or a great part of the refuse is rubbed off the grain. The stones of these mills are not cut into channels as in flour-mills, and they are kept at such a distance that the grains are not cut or broken, but merely deprived of the refuse that may adhere to the surface. From the stones it is received into another inclined sieve, where the heavier parts of the refuse fall from it, and thence into a box or hopper containing fanners, which separate the remaining lighter portions. It is then in a proper state for the flour-mill.

Millstones

(492.) *Millstones.*—The description of stone most commonly used in grinding wheat is imported from France, and is usually known by the term French burrs: it is a porous silicious mineral, and so very hard, that a pair of millstones of this material will last for twenty or thirty years at full work before they are worn out. For grinding barley, oats, and rye, a species of stone from the Peak of Derbyshire is often used; it can be obtained for about one quarter the price of the French burrs, but is so much inferior to it in hardness, that it wears out in much less time, and requires repeatedly to be dressed, which is a troublesome operation, and attended with considerable loss of time. It is, however, very common in wind-mills to have one pair of French stones, which are used for wheat, and one of the Peak stone, which are used for oats or rye, or any other description of grinding that may be required.

(493.) In the year 1800, in consequence of the difficulty of obtaining French burrs during the war with France, the Society for the Encouragement of Arts, &c. offered a premium of a gold medal, or one hundred pounds, for the discovery of a quarry producing stones similar to the French burrs; and adjudged it at the next sessions to Mr. Richard Bowes of Conway in North Wales, who discovered a stone of this description in a quarry situated in the Corporation Liberties of Conway. The vein was about eight feet wide, composed of a mixture of quartz and cherts, which by exposure to the air became very hard. Several stones of this description were manufactured and worked in several parts of the Kingdom, and appear, from the evidence given to the Society, to have answered the purpose very well: they are, however,

VOL. VII.

evidently inferior to the French burrs, and they have not been brought into general use.

Machinery

A stone for this purpose was also discovered by Mr. James Brownhill, in the great basaltic rock of the Alley Craig, near Stirling, who examined the texture of several masses of the stone, and found a species which appeared fit for the grinding of wheat; a sample of which was built into a pair of stones under his direction by Mr. Alexander Ball, agent to the Alloa mills, in the same manner as the French burr, and gave such satisfaction to the customers of the mills, as to induce the Alloa mill company to have another pair built, and totally to lay aside the French burr millstones. The uniform texture of this species of stone gives it an advantage over the French, which is at times so excessively porous as to make it necessary to fill up the cavities with a preparation of alum, an operation attended with some expense; but it is, as well as the stone before described, so inferior to it in hardness, that in cases where great velocity of rotation is required, as in steam-mills, the great wear and constant repair attending it cause it to be but little adopted.

All the millstones which are found preserved from ancient times are small, and very different from those in use in the present day. Thoresby mentions two or three such found in England among other Roman antiquities, which were but twenty inches broad; and several others we have described in the Historical sketch preceding the present section. The runner or loose millstone in this sort of grinding was usually very heavy for its size, being as thick as broad, and is the same which is expressly prohibited in Scripture to be taken in pledge, as, lying loose, it was more easily removed. The Talmudists have a story that the Chaldeans made the young men of the captivity carry millstones with them to Babylon, where there seems to have been a scarcity of such stones at that time; and hence probably their Paraphrase renders the text, "have borne the mills or millstones," which might thus be true in a literal sense. They have also a proverbial expression of a man with a millstone about his neck, which is used to express a man under the severest weight of affliction. This also must plainly refer to this small sort of stones.

(494.) *Construction of millstones.*—Millstones are generally composed of a number of pieces attached together by a strong cement, and further secured by iron hoops passing round the circumference. The French stones are always made in a number of pieces in consequence of the difficulty of obtaining large masses of sufficient hardness for the purpose. The cement made use of is however of so hard a nature, that with the assistance of the iron hoops they are rendered as secure, and even more secure, than any other kind of stones.

Construc-
tion of
millstones.

In order to cut and grind the corn, both the upper and lower millstones have grooves or channels, *a a a*, &c., fig. 1 and 2, plate xxxix., cut obliquely from the circumference, to about an inch or an inch and a half from the centres, with others parallel to them, which terminate in a line of a radius to the centre. The number of channels is varied by different millers: in the one exhibited in the drawing there are eight master or long channels, or, the stone is said to be divided into eight quarters, and each quarter has four smaller channels. Sometimes, however, the stones are divided into twelve, and even more quarters, in which case there are usually not above two or three besides the master channel in each quarter. The furrows are cut

Pl. xxxix.
Fig. 1, 2.

Manufac-
tures.

perpendicularly on one side, and obliquely on the other, into the stone, which gives each furrow a sharp edge; and being cut the same on both stones as they lie on their backs, when the upper stone is reversed in its place and in motion, these sharp edges meet each other, and, as before described, cut the corn after the manner of a pair of scissors, which makes it grind the easier when it falls upon the places between the furrows.

It is necessary here to observe that when the furrows are worn shallow, and new dressed with the chisel, the same quantity of stone must be taken from every part of the grinding surface, that it may have the same convexity or concavity as before. As the upper millstone should always have the same weight when its velocity remains unchanged, it will be necessary to add to it as much weight as it has lost in dressing. This is usually done by covering its top with a layer of plaster of Paris, of the same diameter as the layer of stone taken from its grinding surface; and as much thicker than the layer, as the specific gravity of the stone exceeds that of the plaster.

Fig. 2.

Fig. 2 is a view of the lower stone for water or steam flour-mills, which has a wooden bush generally fixed into a hole in the middle of it. Into this a steel pivot is fixed upon which the upper millstone revolves; but in wind-mills, where it is necessary to be continually changing the distance of the stones from the variability of the velocity of the wind, the shaft or spindle of the upper stone passes through a hole in the lower one, and has a bearing in a beam which is acted upon by a governor, so that when the velocity increases, the balls fly open, and, by the action of the levers, lower the upper stone; otherwise, if the stones were at the same distance when going at a great velocity as when going slow, the corn would be driven through the mill without being sufficiently ground. In fig. 1, which is a representation of the under side of the upper millstone, *b b* are two sockets which fit upon the arms of a cross attached to the lower extremity of the shaft, so that the millstone is suspended and takes a horizontal position when put in motion, by reason of the centrifugal force.

Bedding
the stones.

(495.) *Bedding of millstones.*—This requires particular attention, as it is requisite they should be kept perfectly level and firm in their bearing, in order to obtain a good quality of flour. They are usually supported upon cross timbers in the flooring of the mill, and adjusted horizontally by means of wedges: of late years, however, cast iron has been used for the framework of the bedding, and the adjustment made by screws, which is found more convenient, as the wedges are often displaced and troublesome to adjust. In the year 1821, the Society for the Encouragement of Arts, &c. rewarded Mr. T. Austen for a method of supporting and adjusting the bed-stone of a corn-mill, which consisted of fixing the stone in a cast iron frame bedded in plaster of Paris, and of one uniform strength. This frame is bedded on another cast iron frame attached firmly by bolts and nuts to the timbers of the mill. This latter frame had three screws in the bottom part placed on the plan of a triangle, and four screws in the sides, by means of which it could be adjusted either vertically or horizontally with great facility. Fig. 3 is a section through the millstones and floor: *a* the bed-stone which is fixed in the iron case *a' a'*; *c c* the adjusting screws on the points of which the stone rests; *d d* screws to adjust sideways; *e e* two beams of the floor on which the cast iron bed rests, the ribs *b b* of the ends being let in level

Fig. 3.

with the surface; *h h* is a flat circle of wood to cover the adjusting screws and bed which is fastened down by the bolts *i i*; *k k* is a case which incloses the stones to prevent the escape of any flour; *n* is an iron cross, termed the damsel, which, in revolving, strikes the shoe *m*, and gives it a motion which causes the corn to pass down, and affords a supply to the millstones in proportion to the velocity of motion; *p* is the vertical shaft which gives motion to the upper millstone *o*, by means of the cross *q*, which is attached to the stone and fits into the upper part of it.

The mechanism of this part will be better understood by inspecting fig. 4, which is an enlarged view of the upper part of the axle *p*. It is made octagonal to fit the octagonal hole of the iron box *s* to the pin *t* upon which the upper stone *o* hangs. Fig. 5 is a side view, and fig. 6 a plan of the iron bar which is fixed in the upper stone; *l l* are cross arms which drop into the cross of the box *s* and keep the stone in its right position while it is suspended on the pin *t*, these cross arms are shaped like an arch, as shown in the figure.

(496.) *Velocity of millstones.*—The great heat which is generated by the too rapid motion of millstones renders the meal of an inferior quality; at the same time it is desirable to obtain as great a velocity as possible in order to produce the greatest effect. The velocity given to millstones should depend upon their diameter and degree of convexity: for, as the centrifugal force, which gives the tendency of the corn and meal to pass out of the mill from the centre to the circumference, is as the square, while the quantity of grinding surface is simply as the velocity, it is necessary, if the velocity be increased, that the convexity or fall be diminished in order to prevent the corn from passing out of the mill not sufficiently ground. Of late years the millstones made use of have generally been smaller and made to go at a greater velocity than formerly. In the mill lately erected in his Majesty's Victualling-yard at Deptford, upon the most improved construction for the purpose of grinding wheat for the manufacture of biscuits for the Navy, the millstones are rather less than four feet in diameter, and make 120 turns in a minute, and have been found to answer perfectly well. Mr. Fabre observes, that the flour is the best possible when a millstone five feet diameter makes from 48 to 61 revolutions in a minute. Mr. Ferguson allows 60 turns to a millstone of six feet diameter, and Mr. Janson 120 to a millstone of four feet six inches: so that great uncertainty seems to exist about the best size and velocity of millstones. Those most usually adopted in the best water-mills of this Country are from four feet six inches to five feet in diameter, and they make from 80 to 100 revolutions per minute; which agrees with the observations of Mr. Fenwick, an excellent practical mechanic of Newcastle, who states that, with these dimensions and velocity, he has always found the best effect.

(497.) *Dressing the flour.*—The separation of the fine and coarse parts of the flour for the different purposes to which it is applied is effected by two Machines of different construction, termed the *Bolting-mill*, and *Dressing Machine*.

The bolting-mill consists of a reel fitted to an axle which revolves with great rapidity; the reel is covered with a cloth composed of a material termed duck, in the inside of which the flour to be prepared is placed. In the box which contains the reel are placed a number of bars of wood, termed beaters, against which the

Bolting-
mill.

Manufac-
tures.

cloth strikes with considerable violence, and causes the finer portions of the flour to be driven through, and thus separates them from the coarser flour and pollard. The reel is generally composed of six bars of wood united by arms passing through the axle, forming, when so combined, a circle whose diameter is generally $22\frac{1}{2}$ inches at the upper end or head, and tapered to $20\frac{1}{2}$ inches at the tail or lower end; but in some mills they are of the same diameter throughout, in which case they are called equal reels, to distinguish them from the taper ones. The bolting-cloth is a cylindrical sieve, and considerably larger in diameter than the reel upon which it is fixed. At each end of the bolting-cloth a strip or band of leather is fastened to it by being neatly sewed, which serves to strengthen the cloth. The leather fixed to the head or upper end of the cloth has a drawing string inserted in it for the purpose of fixing it over the pin at the head of the reel; and at the bottom of the bolting-cloth six hoops are attached to the tail leather, each of which being brought to the end of a bar, drops into a notch made to receive it, and so fixes the cloth at the tail of the reel.

The reel is placed in an inclined position, and the beaters are placed parallel to the bars of the reel at equal distances around, and about half an inch distant from the bars of the reel when they stand opposite each other. The reel when set to work is turned with such velocity that the centrifugal force would throw out the bolting-cloth to its full extent were it not intercepted by the beaters, so that whilst a constant stream of meal is entering the bolting-cloth at the upper end, the continual and repeated blows of the cloth against the beater force the flour through the meshes of the cloth, which, without the action of the beaters, would soon be clogged or choked up. The offal, consisting of bran, pollard, and sharps, are, by the inclination of the reel, delivered at the tail end of the bolting-cloth.

The complete success of the operation depends very much upon the rapid and powerful vibration of the bolting-cloth, and the equable manner of its action upon the beaters. Both of these requisites, by the common mode above described, of fastening the hoops to the bars of the reel, are very imperfectly arrived at, the only vibration being obtained from the elasticity of the cloth, while, from the stretching of the leather at the head and tail, and the hoops, with various other causes, the cloth frequently takes an eccentric position upon the reel, performs its work but slowly and imperfectly, and when going at a great velocity, or not regularly supplied with meal, is sure to be partially injured or torn to pieces.

To obviate these inconveniences, Mr Jam Ayton, of Trowse, in the County of Norfolk, took out a patent for an instrument or spring to be applied to bolting-mills, for the purpose of facilitating and improving the dressing of flour, and other substances, of which a drawing is given in plate xxxix. Fig. 7, 8 are representations of the instrument prepared to be fastened by two screws to the iron axle of the bolting Machine. A is a cylindrical ring of iron, into which are rivetted the six elastic arms or springs *a b c d e f*. The extreme end of each arm is formed into a broad hook, to receive a loop fixed to the tail leather of the bolting-cloth. These hooks are neatly rounded and made very smooth to prevent the loops being injured when the spring is in action. B is a centre ring, which is also cylindrical; it receives the ends of two conical pointed screws *g* and *h*,

which are secured in the outer ring A, and in this way form two centres of a universal joint; *i* and *k* are two conical pointed screws secured in the centre ring B, which enter conical holes in the centre socket *c*, exactly at right angles with the screws *g* and *h*. The socket C is made with a square aperture in its centre to fit upon the square iron axle of a bolting reel, where it is made fast by the fixing screws. When this instrument is fixed upon the proper part of the axis of a bolting reel, and the loops at the tail leather of the bolting-cloth are placed in the hooks, at the extremity of the arms or springs, instead of being drawn into the notches at the ends of the bars of the reel, a very constant and uniform tension is kept upon the bolting-cloth, so that when set to work, each part of it will strike the beaters with equal force; it preserves a proper degree of vibration, and thereby causes the mill to perform its work in a more regular and perfect manner. Mr. Ayton made several additional improvements in the bolting Machine, in order that his instrument might be used to the best advantage. Fig. 9 represents a side elevation of a bolting Machine on his construction, the inclosing doors being removed in order that the internal parts may more easily be seen. A A A A represent the bars of the frame upon which the bolting Machinery is placed. B B is a wrought iron axis, upon which the mace C or socket is fixed by a screw; *a a*, &c. are six semicircular arms of iron, only four of which are seen in the figure. These arms are fixed to and support a wooden cylindrical rim, and thereby form a frame to fix a net upon, and when the meal enters in a stream, it has the effect of spreading or dispersing it equally over the upper and internal surface of the bolting-cloth; *b b* are two arms of iron fixed also to the mace C; two similar ones are fixed in the same mace at right angles. D represents another mace fixed on the same axis, having four bars or arms *c c c c* similarly placed and fixed in it; *d d* represent two pieces of duck five or six inches wide, fixed at each end to the arms or rods *b b* and *c c*. Two similar pieces of duck are fixed to the other arms, the edge of one being seen at *e e*. Each of these pieces is made to extend about an inch beyond the end of the arm, and the whole constitutes a winnow, over which the bolting-cloth is drawn, and being made fast to the rim D by the running string before named, and the loops fixed to the tail leather placed in the hooks of the patent spring, the most perfect and equable tension will be produced upon the bolting-cloth.

In using the bolting Machine, it is sometimes necessary to adjust the beaters either nearer to the bolting-cloth or further distant from it as occasion may require. The manner in which this is effected in Mr. Ayton's bolting-mill will be seen in fig. 10, which represents an end view of the Machine, corresponding with the elevation. E E is a cast iron plate or ring, let into a recess formed in the tail board where it is confined by the brackets *f f f f*, in such a manner as to be at liberty to move or turn concentric with the axle B of the reel. Another plate or ring, exactly similar in every particular, is let into a recess in the head board. These plates have in each of them six grooves, (as shown at *g g g*, &c. in the figure) equally distant from each other, made eccentric with the ring; and on the edge or periphery of the ring or plate, a few teeth or cogs are formed which engage a pinion H fixed on the spindle I. A similar pinion is fixed on or near the other end of the spindle which engages teeth on the cast iron plate let

Machinery.

Fig. 9.

Fig. 10.

Fig. 7, 8.

Manufac-
tures.

into the head board, and when the spindle is turned either way, both the plates move simultaneously; six radial grooves or slits are made in the tail board, and six similar grooves are made exactly opposite those in the head board; *iii*, &c. represent six cylindrical bolts with pentagonal heads, the other ends of which are screwed into the extremity of each beater, the bolts being previously passed through the eccentric grooves of the circular plates and radial slits or grooves in the head and tail board.

By this contrivance, the distance of the beaters may very speedily be adjusted, and by the use of a winnow instead of the common reel, the injurious effects of the reel bars upon the cloth are said to be greatly avoided. As the extreme edges of the four pieces of duck pass within about three-fourths of an inch of the beaters there is always a space of eight or ten inches in the centre round the axle, from the inner extreme edges of the winnow; and as this part of the Machinery of a bolting-mill revolves with great rapidity, the pieces of duck set the air in very brisk motion, which tends very powerfully to force the flour through the meshes or interstices of the bolting-cloth, while the spring keeps the cloth in a constant state of tension and tremulous motion, thereby preventing any tendency which the flour may have to clog, to fill up the interstices of the cloth.

By this improved bolting-mill, it is stated that four sacks of flour may be dressed in one hour, whereas, by the common one, two and a half or three sacks per hour is considered the average work.

Dressing
Machines.
Pl. xxxix.
Fig. 11.

(498.) *Dressing Machine*.—A Machine of this description is represented in fig. 11: it consists of a hollow cylinder or frame A B covered with wire cloth of different degrees of fineness, the finest being at the end A which is the most elevated, the axle of the cylinder being inclined in the same manner as that of the bolting-mill. Within the cylinder, which is stationary, a reel is placed with its axle exactly in the centre of the cylinder, and to the rails of this reel are attached hair brushes, which, as they revolve, brush against the interior wire surface of the cylinder. The Machine is provided with a shoe or jigger, very similar to that of the millstones, to cause a regular supply of flour or meal through a spout S from the floor above, to which it is elevated by the sack tackle after being ground. The meal, being by this means gradually fed into the cylinder, is, by the motion of the brushes of the reel, sifted or rubbed through the wire. The finest of the flour will of course go through at the upper end, but no other kind, the second through the next division, and so on till the bran falls out through the end of the cylinder, being too coarse to go through any of the wires. The cylinder is inclosed in a tight and close box to prevent waste by the flour flying about, which box is divided into a number of partitions, to collect the flour of different degrees of fineness. The number of partitions and their position are varied by different millers; the general number is however four, and the flour which they receive is termed, first, second, third, and pollard. The wire cloth is manufactured in lengths of 4 feet and $9\frac{1}{2}$ inches in breadth; the length of the cloth covers the circumference of the cylinder, and is fastened down by the wooden ribs *iii*, &c. three of which are situated in $9\frac{1}{2}$ inches, or the breadth of one piece of cloth. The degree of fineness with which the cloth is manufactured is with 64, 60, 38, and 16

Machinery.
meshes to the inch, the arrangement of which is commonly as follows. The first length is of 60 meshes to the inch, being a slight degree coarser than the next, which has 64. This arrangement is found desirable, because when the meal first enters the cylinder it is still moist and warm from the stones and is liable to clog the fine wires; moreover, at this part of the cylinder, the brushes have scarcely acquired their full action, so that, although the wire is coarser, a finer sort and less quantity of flour passes through than in the second length. The first partition is generally placed at the end of the second length of cloth, forming a division to receive the finest description of flour, termed *firsts*. The next length on the cylinder is of cloth of 64 meshes to the inch, which, although of a greater degree of fineness than the last, receives through it flour of an inferior quality, termed *seconds*, which is collected into the second division of the Machine; sometimes an additional length of wire is added to this division of 56 meshes to the inch; the next length is 32 meshes to the inch, and the last 16: the product of these last is collected separately, and forms the thirds flour and pollard. The bran, which is composed of the husks of the corn, and which is too large to pass through any of the wires, passes out at the end of the Machine. The divisions of the case or box are not confined in their position, so that the miller, by shifting them, can obtain flour of any degree of fineness to suit the taste of his customers. The pinion for turning the dressing Machine is generally made so as to turn either way, the object of which is, that when the Machine has been running for some time in one direction and the brushes become bent on one side, the motion may be reversed to give them an equal wear on the opposite side.

In consequence of a liability of the meshes of the wire to become clogged, a patent was taken out by Mr. John Smith of Bradford, in Yorkshire, for the use of a brush to be applied to the exterior of the cylinder. It is of a circular shape, and made free to revolve upon a spindle attached to a projected part of the box or frame containing the Machine. The cylinder is made to revolve by the Machinery which causes a revolution of the brush, and consequently the hairs to penetrate the meshes of the wire cloth.

Mr. Smith also introduced the use of cast iron instead of wood in the construction of the ribs of the cylinder, which is certainly a considerable improvement, as it admits of a much readier method of fixing the wirework.

The dressing Machine is of more recent invention than the bolting-mill, and is now more commonly employed than the latter, although, in all large mills, both Machines are employed. The bolting-mill only produces two descriptions of meal, *viz.* flour and pollard or bran, so that, before the use of the dressing Machine, it was necessary to have several of them, with cloth of different degrees of fineness. They are generally employed when the stones are first dressed; the pollard which comes from the dressing Machine having then a good deal of flour mixed with it, which is very readily separated by the bolting-mill: in such cases it is very common to grind the pollard a second time with a pair of dull stones which have become unfit for grinding corn without dressing them again. The meal being then dressed in the bolting-mill, produces a considerable quantity of seconds flour.

(499.) *An Account of the Quantities of all Sorts of Grain, Meal, and Flour, stated in Quarters, which were imported into Great Britain from Ireland, from the Islands of Man, Guernsey, Jersey, Alderney, and Sark, and from Foreign Parts, in each Year, from 1820 to 1831, both inclusive.*

Years.	Barley and Barley Meal, (including Beer or Bigg.)				Beans and Bean Meal				Buck Wheat.				Indian Corn and Meal.			
	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.
	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.
1820	87,095	1,248	28,671	117,014	8,446	12	10,760	19,218	Not treated as corn in these years.	1	....	5,192	5,193	....	213	2,981
1821	82,884	2,048	13,547	98,479	4,959	....	140	5,099								
1822	22,532	134	19,024	41,690	7,235	....	....	7,235								
1823	19,274	294	2	19,770	5,540	1	227	5,768								
1824	44,699	2,529	26,364	73,592	5,791	....	2,086	7,877								
1825	154,256	4,055	425,179	583,490	11,355	....	10,744	22,099								
1826	14,885	1,945	278,079	344,909	7,190	....	123,719	130,909								
1827	67,791	152	205,889	273,832	10,037	....	142,711	152,748								
1828	84,204	5,254	166,254	255,712	7,068	17	74,465	81,550								
1829	97,140	4,650	275,671	377,461	10,444	80	44,970	55,494								
1830	189,745	6,471	136,582	332,798	19,053	5	16,935	35,993	....	....	6	28	7,519	....	7,547	....
1831	185,409	5,499	376,423	567,331	15,039	19	23,370	38,428	....	....	6,694	563	44,702	....	45,265	....
Years.	Malt.				Oats and Oatmeal.				Peas.				Rye and Rye Meal.			
	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.
	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.
1820	....	....	....	....	916,250	2,136	681,514	1,599,900	447	28	8,452	8,927	134	4	12,102	12,240
1821	....	....	....	....	1,162,249	1,901	101,299	1,265,449	2,474	133	578	3,185	550	..	111	661
1822	....	....	....	....	569,237	374	55,218	124,879	728	....	425	1,153	353	..	....	353
1823	....	....	....	....	1,102,487	1,498	27,467	1,131,452	586	1	....	587	198	..	....	198
1824	1,173	....	....	1,173	1,225,085	575	487,411	1,713,191	756	17	4,808	6,581	112	6	848	966
1825	10,826	....	....	10,826	1,629,856	1,209	204,459	1,835,524	1,431	17	16,666	18,114	220	1	3,847	4,068
1826	1,202	....	....	1,202	1,303,734	78	1,124,215	2,482,027	1,452	1	64,761	66,214	77	9	67,878	67,964
1827	571	....	....	571	1,343,267	522	1,740,817	3,084,606	1,372	4	34,492	35,868	256	..	29,365	29,621
1828	853	....	....	853	2,075,631	2,165	164,339	2,242,135	4,944	98	52,770	57,812	1,424	3	29,560	30,987
1829	2,011	....	....	2,011	1,673,628	2,176	539,094	2,214,898	4,503	26	36,781	41,310	568	9	65,901	66,478
1830	2,820	....	....	2,820	1,471,252	1,087	503,771	1,976,110	2,520	25	34,762	37,307	414	..	45,157	45,571
1831	10,888	....	....	10,888	1,655,934	2,831	619,530	2,278,295	4,663	22	59,537	64,222	515	..	91,820	92,335
Years.	Wheat and Wheat Flour.				Total of all Sorts.											
	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.	From Ireland.	From the Isles of Man, Guernsey, &c.	Foreign and Colonial.	Total.
	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.
1820	404,747	1,036	585,426	996,479	1,407,120	9,734	1,332,116	2,758,970								
1821	569,700	8,073	129,611	707,384	1,822,816	12,155	245,499	2,080,470								
1822	463,004	4,486	43,112	510,602	1,063,089	4,994	120,810	1,188,893								
1823	420,068	8,257	15,694	424,019	1,528,153	10,251	43,390	1,581,794								
1824	356,408	4,421	80,762	441,591	1,634,024	7,568	602,470	2,244,065								
1825	396,018	7,551	383,977	787,546	2,203,962	12,833	1,044,945	3,261,740								
1826	314,851	7,258	575,018	897,127	1,693,391	9,291	2,240,038	3,942,720								
1827	405,255	5,968	300,645	711,868	1,830,314	6,646	2,604,699	4,441,619								
1828	652,584	17,179	741,148	1,410,911	2,826,988	24,716	1,269,280	4,120,984								
1829	519,493	8,598	1,667,479	2,195,970	2,307,817	15,539	2,672,210	4,995,566								
1830	529,717	15,491	1,659,939	2,205,147	2,215,549	23,079	2,404,671	4,643,299								
1831	557,520	14,266	2,297,096	2,868,882	2,430,531	22,637	3,519,172	5,972,340								

An Account of the Quantities of all Kinds of Grain and Flour brought coastwise, or imported from Ireland and Foreign Parts, into the Port of London, from Michaelmas to Michaelmas in each Year, from 1820 to 1831, both inclusive.

Years.	Wheat.				Barley.				Malt.				Oats.			
	English.	Irish.	Foreign.	Total.	English.	Irish.	Foreign.	Total.	English.	Irish.	Foreign.	Total.	English.	Irish.	Foreign.	Total.
	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.
1820	337,751	18,138	235,482	641,371	278,780	8,899	5,865	293,544	195,878	..	....	195,878	584,965	191,912	238,850	1,051,727
1821	358,172	85,631	42,687	486,484	217,273	14,999	2,850	234,922	214,673	..	....	214,673	507,279	142,832	219,020	869,131
1822	500,443	11,712	42,196	554,351	236,775	2,995	20,277	260,047	221,108	..	....	221,108	681,082	57,851	74,973	813,906
1823	387,282	5,895	1,460	394,637	173,349	2,917	....	176,266	232,309	..	....	232,309	620,558	287,756	8,665	916,979
1824	347,866	141	6,260	354,267	191,168	1,781	1,810	194,759	233,638	55	....	233,638	537,797	142,553	226,392	906,742
1825	394,375	18,796	117,790	530,961	281,906	5,187	106,472	393,565	256,813	30	....	256,813	550,175	318,515	190,787	1,059,477
1826	273,050	670	173,975	447,677	181,860	637	165,084	347,581	275,787	..	....	275,787	192,667	297,374	329,816	1,119,857
1827	239,405	2,314	167,313	409,042	187,197	..	115,848	303,045	241,756	..	....	241,756	120,625	42,254	1,209,153	1,372,032
1828	290,975	21,635	110,492	423,101	212,550	3,845	8,369	224,764	229,934	..	....	229,934	272,411	635,803	90,006	998,220
1829	173,865	14,285	1,154,595	1,342,745	211,479	148	123,878	335,505	226,723	..	....	226,723	480,424	371,520	387,593	1,239,517
1830	219,316	5,571	634,175	873,488	210,535	750	39,965	344,729	218,261	..	....	218,261	193,576	304,998	264,689	900,137
1831	191,298	7,827	700,188	908,517	228,793	3,990	152,745	396,849	257,504	..	....	257,504	263,153	288,070	388,177	1,082,654

TABLE continued.

Manufactures.

Mechanical Processes.

Years.	Rye.				Beans.				Reas.			
	English.	Irish.	Foreign.	Total.	English.	Irish.	Foreign.	Total.	English.	Irish.	Foreign.	Total.
	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.	Qrs.
1820	833	..	...	833	63,366	..	4,837	68,203	42,641	..	7,685	50,326
1821	1,374	159	...	1,533	102,016	..	1,630	103,646	52,270	..	...	52,270
1822	3,153	80	...	3,233	109,347	..	...	109,347	61,447	..	...	61,447
1823	465	25	...	490	81,905	10	...	81,915	43,286	..	42	43,328
1824	2,669	..	670	3,339	82,849	..	256	83,105	55,628	..	2,676	58,304
1825	507	15	...	522	92,274	..	1,638	93,912	59,399	..	2,843	62,242
1826	382	3	685	1,070	73,407	..	10,772	84,179	43,851	..	14,467	58,318
1827	369	..	30,706	31,075	45,030	..	94,476	159,506	34,560	..	41,002	75,562
1828	1,431	..	745	2,176	68,886	..	23,540	92,426	47,217	..	4,824	52,041
1829	1,753	26	20,477	22,225	73,010	58	12,283	85,293	44,047	..	34,146	78,193
1830	...	..	...	...	73,139	..	5,081	78,584	43,811	..	4,903	49,217
1831	671	..	17,783	18,454	76,336	90	3,091	79,558	35,559	..	23,260	58,972
	Linseed.				Rapeseed.				Flour.			
	Sacks.	Sacks.	Barrels.		Sacks.	Sacks.	Barrels.		Sacks.	Sacks.	Barrels.	
1820	8,654	..	93,037	101,691	2,907	4,600	3,024	10,531	426,315	1,386	37,119	464,280
1821	813	120	62,292	63,225	5,197	620	...	5,817	411,130	13,285	17,803	422,218
1822	957	320	83,816	85,093	14,862	2,019	220	17,101	440,040	5,345	710	450,095
1823	878	..	80,593	81,471	7,495	1,045	390	8,930	495,915	1,864	4,620	502,399
1824	1,022	65	87,695	88,472	3,711	6	8,499	12,216	437,185	1,141	18,905	457,231
1825	650	..	113,091	113,741	1,251	..	9,563	10,814	521,774	9,599	8,880	540,253
1826	...	..	97,979	97,979	836	766	14,667	16,269	479,638	100	2,528	482,266
1827	440	..	123,545	123,985	138	150	14,853	15,141	445,589	349	4,751	450,689
1828	1,395	..	114,023	115,418	1,083	70	9,017	10,170	453,814	7,472	7,007	468,293
1829	532	..	82,067	82,599	1,111	..	8,971	10,082	373,868	32,283	78,642	484,793
1830	212	..	88,956	89,168	...	..	...	...	398,021	15,535	62,190	475,746
1831	...	..	133,907	133,907	1,992	..	14,249	16,241	363,167	12,554	251,282	627,003

Various kinds of corn-mills.

(500.) *Mills for bruising grain, malt, &c.*—The mill described in the preceding section, is one of the most complete in England and of course in Europe, and from this to the small hand-mill there are necessarily many gradations; there are also gradations in the operations of grinding. In the mill we have described, the corn is reduced to its ultimate state of fineness; but such means of perfect grinding are not necessary in all cases, such as in the preparation of barley for making pearl barley, for breaking or grinding peas, beans, &c. for cattle, bruising malt for brewing, &c. But as the processes in all these cases differ rather in degree than in principle, it will not be expected that we should enter into a minute description of these kinds of mills, which would occupy our pages and our plates with little interest to the reader; in general the principle is the same, and it will readily be comprehended that as less accuracy of grinding is requisite, so some of the means employed in the more perfect mills may be omitted, and the process rendered thereby so much more simple, cheap, and expeditious. It will perhaps only be necessary to observe that the malt-mill is not always of the grinding kind, the malt being merely made to pass between two rollers to bruise it. It is, however, frequently preferred in a ground state, and then of course the grinding process must be had recourse to.

Fulling-mill.

(501.) *Fulling-mills.*—The fulling-mill in manufactures is a Machine employed for washing, scouring, or fulling cloth or other material, with a view not only of cleansing it, but also of rendering it thicker and more repellent of rain, &c. The practice of fulling cloth is of considerable antiquity. Pliny states that one Nicus, the son of Hermias, was the first inventor of the art of fulling, who was a Governor in Greece in the time of the

Romans; it is therefore probable that the fulling-mill, in point of antiquity, stands next after the corn or flour-mill.

The process of fulling consists in constantly agitating and exposing new surfaces of the cloth or material under operation to the action of water or other menstruum with which the goods to be operated upon are constantly supplied. This is performed by two or more beaters or mallets, which are successively raised by the action of a wheel, commonly of a water-mill, and let fall with their weight upon the cloth, which they strike and turn over in the trough in which it is placed, at the same time a stream of water is constantly passing through the trough to carry off the dirt and impurities which are loosened from the cloth by the agitation of the mallets, or, as they are technically termed, the *stocks*.

These stocks are formed after the manner of a mallet, that is to say, with a long wooden beam or handle several feet in length; the head of the stock also resembles the head of the mallet, being likewise a heavy block of wood, but formed to a circular arc behind, corresponding to the circle described from the centre of suspension of the handles and to the circular case or trough in which they work. But the end of the mallet which strikes the cloth is not left flat, but formed into two or three projections like steps, so that on striking the cloth it may double and bend it in various directions. The shaft of the stock projects on one side beyond the head, and a sort of cam wheel fixed on the axis of the wheel shaft as it revolves keeps continually raising the stocks and letting them fall on the cloth, while a pipe is constantly supplying the water which is running off, carrying with it the dirt which has thus been removed. Many of these stocks are ranged in a line, and as

Process of fulling cloth.

Fulling-mill.

Manufac- tures. stated, they may be worked either by a water wheel or steam engine; in the former case the axle of the water wheel is employed to move two or three pair of stocks according to their weight and dimensions, while the others receive their motion from one or more similar shafts turned by cog wheels from the shaft of the water wheel. We have not thought it necessary to give a figure of this mill, which is so very simple in its construction and operation as to be easily comprehended without one.

Fulling with soap.

(502.) In fulling cloth with soap, if it be coloured, a piece of forty or fifty yards is laid in the trough in the usual manner, but without soaking. To full this, about fifteen pounds of soap are required, one half of which is to be dissolved in two pails of river or spring water made as hot as the hand will well bear it. This solution is poured little by little upon the cloth as it is being laid in the trough, and with this it is to be fullled for about two hours, after which it is taken out and stretched. The cloth is then immediately returned to the trough without any fresh soap and then fullled for two hours longer. It is then again taken out and well wrung, to press out as much as possible of the grease and other impurities.

After the second fulling, the remainder of the soap is melted, as the former was, and cast at four different times on the cloth, taking out the same every two hours to be stretched, and to relieve the plaits and wrinkles it has acquired in the operation; when it is perceived to be sufficiently fullled and brought to its proper quality and thickness, it is scoured for the last time in hot water, keeping it in the trough till it is quite clean.

As white cloths full more easily than coloured cloths, they require less time, and do not require generally more than two-thirds the quantity of soap.

Fulling, however, which we have hitherto spoken of as applicable to cloth, is practised, although somewhat differently, on other materials, as stockings, caps, and other woollen goods, as also in the manufacture of hats.

The fulling of stockings and caps is of course done on a smaller scale, and may be effected either with the feet or hands, or on a kind of rack or wooden Machine armed with teeth of the same materials, or with horses' or bullocks' teeth. The ingredients made use of are urine, green soap, white soap, and fullers' earth, but water softened with chalk is said to be preferable. Woven stockings are fullled with soap alone, and knit ones with the ingredients above mentioned.

Fulling the felt of hats.

(503.) The fulling of the felting in hat-making, has for its object the intimate connection of the fibres, and a more perfect and durable cohesion of the whole mass. For this purpose the mere mechanical act of pressure is insufficient. Experience has long shown that in this process it is necessary to make use of a bath of water heated nearly to boiling, into which are put from ten to fifteen pounds of lees of wine for each hundred pounds of water, and the heat should be kept up during the whole time of working, and every three or four hours a fresh supply of lees is added. Into this bath the workman plunges his felt and begins the second process. The felt is dipped in, and immediately again taken out and squeezed, bended and rolled, by pressure, in different directions, sometimes with the hand defended with leather, and sometimes by means of a roller or other similar instrument. The immersion and working of the felt are repeated and continued till the stuff is well condensed and has acquired the required solidity.

The operation of fulling is employed to form a dense

and compact stuff with the fibres of hair, and to determine the intimate cohesion of its component parts; and since the mere mechanical operation is not sufficient for this purpose, even with the assistance of a water bath at the boiling heat, without the addition of lees as a necessary condition, this last must be considered as a chemical solvent, which acts directly on the substance of the hairs themselves, and produces, either by softening or swelling them, an alteration necessary to insure the cohesion of the different fibres of the stuff. But the lees being composed of the mucilaginous and colouring parts, which are separated, together with a great quantity of tartar, or the acidulous tartrate of potash, it became necessary to ascertain, in a positive manner, what might be the principle of its action. The Editor of the *Encyclopédie Méthodique* affirms without hesitation, that it is the alkali or potash of the lees which determines the fulling. "But in order to show (says Mr. Colmet) how erroneous this opinion is, nothing more is necessary than to dip a piece of blue paper into the bath, by which the former becomes instantly red; and if, after several hours' work the state of the bath be again examined, it is found that the acidulous tartrate of potash is partly exhausted, and the workmen soon perceive, from the difficulty of continuing their work, that a new quantity is required to be added. And again, if we consider the sparing solubility of the acidulous tartrate of potash in cold water, it is easily seen why in this process the water must be kept nearly boiling. Whence it is evident that it must act by the portion of acidate which it contains." Hence our author was induced to think, that the sulphuric acid might be advantageously substituted in the place of the lees; and as 12 pounds of lees are usually added to 100 of water, he estimated by approximation that one gross of sulphuric acid would be equivalent to at least one pound of the lees, and consequently that 12 gross of sulphuric acid would be sufficient for 100 pounds of water. His conjectures were soon confirmed by experiment, and after a fair trial it was ascertained that the use of the sulphuric acid is much preferable to that of wine lees; that it is not only much more economical, but still more convenient in the use; and, what is yet more important, that the health of the workmen is not injured by the excess and duration of the heat, the thick vapours, and the disgusting odour, which exhale from the bath, particularly when the lees have been altered by mouldiness and putrefaction, which is very common in these manufactories. When the sulphuric acid is employed, it is useless to keep the bath nearly boiling, as was formerly done. A degree of heat of 25 or 30 degrees (90° or 100° of Fahrenheit) is sufficient for good fulling. The saving of fuel is an object of importance in manufactories, and as very little fire is necessary when sulphuric acid is used, caldrons of lead may be substituted instead of copper boilers, the first cost and annual repair of which are very considerable.

The felts prepared by this new process are also of a very superior quality to those which have been worked in the bath with wine lees. In fact, the mucilaginous and colouring matter of the lees, which are suspended in the bath, penetrate the texture of the stuff, and adhere with more or less force; and when, after having passed the hats through the dye, they are beaten, a fine black dust flies off in great abundance, which not only weakens the texture of the felt, but by diffusing itself through the manufactory greatly incommodes the work-

Machinery.

Manufac-
tures.

men, and frequently occasions coughs and disorders of the throat.

"Hats felted in this manner," says a manufacturer who had adopted this process, "are not only clear of the powder which abounds in the others, but they take the dye better and are cleaner."

Oil-mills.

Oil-mills.

First pro-
cess de-
scribed.

(504.) The term oil-mill is applied to mills for expressing the oil from fruits or grains. In England they are generally made use of for the manufacture of oil from linseed and rapeseed, which are the produce of almost every County. A great number of oil-mills are to be met with in Hull and other parts of Yorkshire, as well as in some other Counties. The process employed by the most careful manufacturers consists in first passing the seed between iron rollers, in order to crack all the grains without separating their parts, after which they are made to pass under two vertical mill-stones, which revolve upon a horizontal bed, where the seeds are further bruised, and are prepared for the process of compression. The use of the iron rollers, however, is not general; in many of the Dutch mills the revolving stones, or *runners*, as they are usually termed, are alone made use of: the rollers are, however, considered, where they have been employed, greatly to facilitate the operation of grinding; for the grains are so hard and smooth that without them they slip away from beneath the running stones, and require much longer time to be crushed than when they are previously broken by the rollers; but these, on the other hand, require so much power that, in small mills, they cannot be worked with the other Machines at the same time. This, however, is little objection to them, for they act with so great rapidity as in a very short time to prepare seed enough for the whole day's work.

Second pro-
cess.

The seed having passed under the running stones until it is sufficiently bruised, is collected in hair bags, and placed in the press, where the oil is extracted by the compressive force of wedges. In olive-oil-mills this process is generally performed by a screw press; but the grains of lint and rapeseed are so excessively hard and smooth on their surfaces, and the fragments of their shells, however broken, form so many little concavities which retain the oil, that a much greater force is necessary than can be obtained by this means. The method of effecting this enormous pressure is by wedges, which are driven into a strong timber framing, containing the seeds as they come from the running stones, previously placed in hair bags for the purpose, as above stated. The wedges are driven by the blows of a heavy pestle, which is raised by the Machinery, and the operation is continued until the wedges are so tight that the pestle rebounds from them three times, when they are judged to be sufficiently driven. The oil thus obtained is considered of the best quality, and is kept apart in a large cistern, which is divided into separate portions by partitions for the different qualities of oil.

The oil cakes of this pressing are taken out of the bags, broken to pieces, and put into the mortars for the first stamping. There the paste is again broken down, and the parenchyma of the seed reduced to a fine meal; thus free egress is allowed to the oil from every vesicle in which it is contained, but it is now rendered much more clammy by the forcible mixture of the mucilage, and even of the finer parts of the meal. When suffi-

ciently pounded, the workman stops the pestle of a mortar when at the top of its lift, and carries the seed to the first chauffer pan, where it is heated to about the temperature of melting bees-wax, (this we are told is the test,) and all the while stirred up by an instrument termed the spatula, which is usually put in motion by the Machinery. After this operation, it is again put into the hair bags, in the manner already described, and the oil which drops from it during this operation is considered the best of the second quality, and in some mills is kept apart. The paste is now subjected to a second pressing, and the oil obtained is that of the ordinary second quality. All this operation of pounding and heating is performed by one workman, who has constant employment by taking the four mortars in succession. The putting the paste into the bags, and conducting the pressing, give equal employment to another workman.

In the mills of Picardy, Alsace, and most parts of Flanders, the operation ends here, the produce of the chauffer being often increased by putting a spoonful or two of water into the pan among the paste. The Dutch, however, take more pains; they add no water to the paste of their first stamping, which they say greatly lowers the quality of the oil. The cakes which result from this pressing, and which are sold as food for cattle, are still fat and soft, and the Dutch very commonly break them down and subject them to the pestles for a second stamping. This reduces them to an impalpable paste, stiff, like clay, which is lifted out and put into the second chauffer pan: a few spoonfuls of water are then added, and the whole is kept for some time at the heat of boiling water, and carefully stirred during the time. Thence it is shifted into the hair bags of the last press, subjected to the greatest pressure, and a quantity of oil of the lowest quality is obtained, sufficient to give a satisfactory profit to the miller. The cake is now perfectly dry and hard, like a piece of board; it is, however, useful to the farmers to whom it is sold.

In this way there is a great quantity of oil obtained which would otherwise be lost, and there are small mills in Holland which have no other employment than extracting oil from the cakes which they purchase from the French and Brabanters, after passing the process of their mills: a clear indication of the superiority of the Dutch practice.

Fig. 1, pl. xl. is a representation of an oil-mill employed for grinding and pressing linseed, rapeseed, and other oleaginous grains. A is a spur wheel, which is put in motion by a water wheel, a steam engine, or any other motive power: it has fifty-two teeth, and engages the wheel B of seventy-eight teeth, which is attached and gives motion to the horizontal shaft C C, termed the tumbling shaft. This shaft is furnished round its circumference with wipers for lifting the pestles, so that each may fall twice during one revolution of the shaft: these wipers, since iron shafts have been introduced, are also generally made of iron. They consist of a square socket, which is fitted on the shaft with arms, having rollers at their extremities, which are found to be a very great improvement, because they not only diminish the friction, but also the wear, which naturally takes place on surfaces rubbing upon each other.

DDDD is the framework which supports the pestles. It consists of four strong uprights, with cross timbers or rails bolted firmly to them. These cross timbers, with small transverse pieces fixed between them, serve

Machinery.

Oil-mill, de-
scription of.
Pl. xl.
Fig. 1

Manufactures.

as guides for the perpendicular motion of the pestles. When the pestles are not required to work they are raised up, so that the lifts are clear of the wipers, by means of levers *a a a*, and these engage the part marked *d*, which is the projection on the side of the lifter. These levers turn upon a joint at *c*, so that by releasing the rope *d d* they will assume a perpendicular position, and the pestle will be left free to work.

I I is a strong block of stone or timber, which contains the press boxes *P P'*, where the grain is squeezed after it has come from the running stones and the six mortars *L L*, &c. where the cakes are put in for stamping, and which are generally hollowed out of the block itself. A board is commonly placed on each side of these mortars standing on its edge and inclined a little backwards; this forms a sort of trough which prevents the seed from being scattered about by the fall of the pestles. The large press box *P*, where the grain is squeezed, immediately it comes from the stones, is also very commonly hollowed out of the block; at all events if it is framed together, the utmost attention must be paid to give it sufficient strength, as the lateral pressure produced by the wedges is enormous. The second press box *M* for squeezing the grain after it has passed under the pestles is generally smaller and not required to be so strong.

The bags of seed *f f* are included between two iron plates united together at bottom in the manner of book lids, the bag is shut up between them, and there are small holes in the bottom of the press at which the oil oozes out into vessels placed to receive it: *w w* are the driving wedges, and *h h* the dischargers or inverted wedges by which the pressure is relieved; the remaining part of the press is filled up by blocks of wood, which rest firmly upon the bottom to prevent their being carried down by the wedges, having thin pieces of wood between them and the wedges to make them slide easier by each other. *R R* are the drivers which strike the wedges that press the oil, and *S S* are the stampers which strike the dischargers or relieving wedges: these are each put in motion by wipers upon the horizontal shaft, in the same manner as the pestles of the mortars: the action of this part will be better understood by inspecting the side elevation of the pestle frame.

In this figure (2) *A* is the section of the tumbling shaft with the two wipers attached to it, which engage the lift or projecting piece *b b* upon the pestle, and raise it for a considerable distance, until it is naturally relieved during the revolution, when the pestle falls with its whole weight in the mortar; it is then again raised by the next wiper, whereby a constant succession of blows is kept up.

Chauffer pan.

(505.) The chauffer pan is seen at *o* in fig. 2; it consists of a small circular copper pan, which is heated by a furnace underneath. *k* is the spatula which is attached to the lower end of a vertical spindle, and which by turning round among the grain in the chauffer prevents it from sticking to the bottom and sides and getting too much heat. In some modern mills the chauffer pan is heated by steam from a boiler, which is much to be preferred, as sufficient heat is thereby obtained for the purpose without any danger of burning the grain, which is liable to happen in a furnace heated by charcoal. The spindle to which the spatula is fixed, is put in motion by a system of wheelwork. In the mill in question, a wheel of twenty-eight teeth upon the main shaft, gives motion to another of twenty teeth upon a

small horizontal axle or shaft; this axle has another Machinery wheel upon it at its other extremity, which engages a wheel upon the spindle of the spatula, and thereby gives a rotary motion of a little less velocity than the main shaft.

l is a lever, one end of which is attached to the pillar *p*, and serves to raise the vertical spindle out of gear when required; it has a hole at *m* through which the spindle passes, and this spindle has in that part a shoulder which rests on the border of the hole, so that by the motion of the lever the spindle may be disengaged from the wheelwork at pleasure. Motion is given to the lever by means of a rope attached to the end, which hangs down by the side of the chauffer pan, so that the man engaged there can very readily raise the spindle out of gear.

In front of the chauffer pan is a basket which tapers downwards and opens below in a narrow slit. The hair bags in which the grain is to be pressed after it has been warmed in the chauffer, are filled by placing them in this basket. The grain is lifted out of the chauffer by a ladle, and put into these bags, and a certain quantity runs from it through the slit in the bottom, which, as before mentioned, is considered of very good quality.

(506.) *Running stones* are the most important part of Running oil-mills, as upon the action of them materially depends stones. the good quality of the oil. They are made to revolve in a strong framework attached to a vertical axis, which also revolves slowly by a large cog wheel at the upper part, which engages a wheel upon the main horizontal shaft. Thus they have two motions, a rotation round their own axis, and that by which they are carried round upon the nether or lower millstone.

In fig. 1, *N N* is the vertical shaft and the framework which carries the millstones. The horizontal axis *O O* of the running stones passes through the vertical shaft and has its bearing in the ears of the framework. The holes in the millstones are made a little wide, and those in the ears of the frame are made oval in a vertical direction, giving great freedom of motion which is necessary for the runner millstones, because more or less of the grain being below them at a time, they must be at liberty to get over it without straining, which might perhaps break the shaft.

The nether millstone is supported upon a firm foundation of masonry, and has a border or hoop which surrounds it to prevent the escape of the grain by the motion of the stones; it has a piece of wood in the centre which carries a brass bush in which the vertical shaft revolves. In order to collect the grain under the stones, there are two rakes or sweeps, which are attached to the framework and revolve on the surface of the nether stone, in such a manner that the grain which is dispersed in all directions by the pressure of the stone, is collected in a ridge in the line of their motion; the inner rake collects grain under the outer runner and the outer rake under the inner runner. The outer rake is also furnished with a rag of cloth which rubs against the border or hoop that surrounds the nether stone, so as to drag out the few grains that might otherwise remain in the corner, and in this manner the grain is always turned over and crushed in every direction. One of the runners is set about two-thirds of its own thickness nearer the shaft than the other; they have thus different treads, and the grain which is a little heaped towards the centre, is of course crushed by both. The inner rake gathers it up under the outer stone in a ridge shape, and the stone passes

Manufac-
tures.

over it and flattens it, and it is gathered again in a ridge by the outer rake: this consists of two parts; the outer part presses close on the wooden border which surrounds the nether stone and pushes the seed obliquely inwards, while the inner part of the rake gathers up what had spread towards the centre. The other rake has a joint near the middle of its length, by which the outer half of it can be raised from the nether stone, while the inner half continues pressing upon it, and thus scrapes off the moist paste. When the seed is sufficiently bruised, the miller lets down the outer end of the rake; this immediately gathers the whole paste and pushes it obliquely outwards to the wooden rim, where it is at last brought to the part left unboarded, and falls through into troughs placed to receive it. These troughs have holes in the bottom, through which a quantity of oil drops all the time of the operation. This part of the oil is directed into a particular cistern, being considered as the purest of the whole, having been obtained without pressure by the mere breaking of the husk of the seed.

Crushing
rollers.

(507.) In the mill above described, rollers for breaking the grains of the seed previous to its passing under the vertical stones not being made use of, it is necessary to give a separate description of them as they are usually adopted in modern mills. They are generally made of cast iron, and truly turned in a lathe, their spindles running in brass bushes fixed in an iron frame bolted down to the framework of the mill. These frames have mortises in them in which the bushes for the rollers are placed with liberty to slide, and adjustable by screws through the ends of the iron frames; by which means the rollers may be set at any distance apart, according to the size and nature of the seed which is to be crushed between them. The rollers are usually made of different sizes, so that their circumferences have different velocities: this gives them a tendency to draw the seeds in, and enables them to perform their work quicker. One of the rollers has a small spur wheel or pinion on its axis which engages the cog wheel on the main horizontal shaft, so that it makes about seven revolutions to one of the main shaft. It conveys its motion by another pinion to the other roller, so that their surfaces roll upon each other and bruise the seed as it passes between them. The pinions of the rollers are sometimes made to have a different number of teeth in order that the surfaces of the rollers may have a different velocity; but this is not necessary if they are of different diameters.

The seed is put into a hopper, supported at some distance above the rollers, and it runs out at an opening in the bottom into a trough called the shoe, which is continually shaken by a piece of wood nailed to it, which rests upon the cog wheel; and by this means the shoe continually feeds the rollers with a small quantity of seed, without any danger of choking them up. It is proper to have a plate of iron attached to some part of the frame, and kept constantly pressing against the rollers, so as to scrape off the seed which may adhere to them. The seed, after having passed between the rollers, falls upon an inclined board placed in a frame beneath them, and is thus shot down in a heap before them, whence it is conveyed by a labourer to the running stones to be crushed. The latter part of the process is exactly similar to that employed in mills where these rollers are not adopted.

(508.) We have thus far described the common processes employed in the manufacture of oil; in many

parts, however, of Holland and England, considerable variations in the process occur, according to the nature of the grain and the quality of oil that may be required. In some of the Dutch mills, a much greater quantity of oil is produced in the grinding without pressure, by having the bed of masonry which supports the lower millstone formed into a little furnace and gently heated. But the utmost care is necessary to prevent the heat from becoming too considerable, as it causes the oil to dissolve too much of the fermentable substance of the seed, and exposes it to the risk of soon growing very rancid. In general this is thought a hazardous practice, and the oil does not bring so high a price.

The seed in this Country is seldom so ripe as to yield any oil from the running stones without pressure; but some millers take a quantity of their best seed from the stones, and putting it into bags give it a moderate pressure by a screw press. The oil thus obtained, is called cold drawn, and is sold at a higher price for the use of cabinet makers, who rub their ornamental work with it to give it a polish. In other mills the cold drawn oil is nothing more than that first obtained from the press, but without heating the seed.

When the seed is very dry, a little water is thrown among it while grinding, which very much facilitates the process. In about twenty minutes a charge of seed will be sufficiently ground, and it is generally taken to the chauffer pan, and submitted to a gentle heat previous to being pressed: this part of the process is, however, very much varied by different millers, according to the nature and state of the seed, and other circumstances, often depending upon the locality of the mill.

The Dutch have been generally considered to excel in this description of manufacture, and the nicety with which that industrious people conduct the whole business is very remarkable. In the oil cistern, the parenchymous part, which unavoidably gets through in some degree in every operation, gradually subsides, and the liquor in every division consists of oil of different degrees of purity. The pumps which lift it out of each division are in pairs, one takes it up from the very bottom, and the other from half the depth. The last only is barrelled up for the market, and the other is put into a deep and narrow cistern, where the dregs again subside and more oil of that quality is obtained.

The produce of oil from linseed has been found, from an average of four months' work of an oil-mill in Yorkshire, to amount to 5616 gallons of oil, from 280 quarters of linseed, generally weighing 30 stone (of 14 pounds each) per quarter, which is at the rate of $20\frac{2}{3}$ gallons per quarter. The greatest produce in the period from which this average was obtained, was 409 gallons from 20 quarters, or $20\frac{9}{10}$ gallons per quarter. The least produce was $19\frac{1}{2}$ gallons per quarter. The number of presses is of course varied according to the power of the mill, some having as many as 10 or 15 in use. A press will generally press seven hundred weight of seed per day, in the first operation, when the grain comes immediately from the rollers; but only two or two and a half hundred weight per day, in the second pressing, as it requires so much more time for the second operation. The wedge press oil-mill has been in use for many years with but little variation in its construction, and is still preferred by the generality of oil pressers, although within a few years several different modes of expressing oil have been invented.

(509.) A patent was taken out by Mr. John Hall of Dart-

Machinery.
Other kinds
of presses.
Other
forms of
mills.

Produce of
oil-mills.

Manufac-
tures.

Hall's
patent oil
Press.

ford in Kent, April 1823, a new press for extracting the oil from seed, which consisted in the employment of cams or eccentric rollers, which by the power of a steam engine are turned round so as to press laterally against sliding plates of iron which form the sides of boxes, that contain the bags of seed to be operated upon.

By this improved apparatus, it is stated that a greater quantity of oil may be extracted than by the ordinary mode, and that the oil cakes left in the bags will be much lighter than those usually produced; it appears, however, not to have got into general use.

Hydraulic
oil Press.

(510.) Bramah's Hydrostatic Press has been applied to the extraction of oil from seeds with considerable success. The first mill on this principle was constructed in 1821, at Bremen, for Mr. Henry Plump, who states that he is satisfied that such mills are the best Machines at present employed for the crushing of seed for oil.

Pl. xl.
Fig. 3, &c.

A representation of this mill or press is given in plate xl., where fig. 5 is a front elevation of one of the oil Presses, fig. 3 an elevation of the two injecting pumps with their frame, cistern, &c., and fig. 4 is an enlarged section of the stop and discharge valves by which the necessary connection is made between the pumps and cylinder.

A A A are brackets supporting the two cylinders and affixed to cast iron plates resting upon the brickwork; B B the press cylinders; C C strong wrought iron bars by which the frame containing the oil bags is secured to the press cylinder. D D is the frame or box which contains the seeds, which is constructed of cast iron with circular ribs at the end *a a*, to increase the strength in the direction in which the pressure is exerted; E is the press piston, which is connected by a strong unwrought iron rod with the cast iron plate or follower F F. The followers have each a friction wheel or roller at the under part, which moves upon the false bottoms of the oil boxes, and are drawn back by means of weights attached to chains passing over pulleys, and rising and falling in a pit made in the brickwork to receive them, as shown by dotted lines. The seeds to be pressed are contained in woollen bags, which are unfolded by horse-hair mattresses, enclosed in leather wrappers, as in the ordinary oil-mill, and are placed in the oil boxes, with cast iron plates grooved at their edges between them, as seen in the figure at *b b b*, &c. Each of the plates have handles *c c c*, &c. at the upper extremity, by which they can be readily lifted out of the oil boxes.

The expressed oil makes its escape through perforations in the false bottoms of the boxes, and flows out by short pipes, technically termed *teats*, made in the sides, to reservoirs destined for its reception in any convenient part of the floor or underground premises. The oil which may occasionally exude at top is prevented from running over by the raised border of the box, and is conveyed to the bottom by a groove at the end of each box communicating with the bottom.

The injection pumps are so arranged as to be worked by a rotary motion from a steam engine, or other first mover, communicated by a toothed wheel to the horizontal shaft *d*. Upon this shaft is attached a crank, which can be adjusted to any length according to required circumstances. Upon the neck of the crank is a connecting rod to communicate motion to the beam above, as seen in the figure, and this beam actuates two injection pumps by means of piston rods furnished with

the usual parallel movements, all of which being of Machinery ordinary and of well-known construction, are not detailed in the drawing.

As the construction of the injection pumps will more fully be described under the article Presses, it is necessary here only to mention some additional contrivances which are required to adjust this principle to the present purpose.

One of the injection pumps is required to have its piston four times the area of the other, so that it injects at each stroke four times the quantity of water produced by the smaller pump, and its safety valve is loaded with a weight proportionally smaller, so that its effect upon the seeds is confined to the commencement of the pressing, when the resistance is not so great, for the purpose of expediting the operation. As the resistance of the seeds increases, the power must likewise be increased, and therefore the lesser pump alone is employed to finish the compression; as, however, both pumps are continually worked by the engine, it becomes necessary, in order to avoid a needless expenditure of power, to relieve the larger pump of its labour, or to reduce it merely to that of the friction arising from working the piston in the cylinder, which is effected by raising the lever and weight of its safety valve, by means of a line connected with it, and passing over pulleys so as to bring the handle at its other end conveniently within the reach of the workman; and thus the water from the large injection pump escapes and falls back again into the cistern. The workman is apprized of the proper time for lifting this safety valve by the rushing noise which the water makes in escaping through it: which effect takes place immediately the resistance afforded by the nut bags exceeds the power of the larger pump. The injection pump may be situated at any distance from the Presses, and the water conveyed from them through strong copper pipes placed underground and continued up through the junction part Z to the stop and discharge valves H and I.

A drawing of the right-hand pair of valves upon an enlarged scale, is shown in fig. 4, in which G is the pipe leading from the junction part Z: H the stop valve which opens and shuts the communication from the pumps: I the discharge valve, having a groove or channel round it, to permit the water to stop from the pumps to the press through the curved pipe *j*. When the Press is to be released, it is only necessary to raise the screw valve I, which allows the water to flow out at the waste pipe K, through which it may escape back to the cistern, or be conveyed to a drain or sewer, as circumstances require. One pair of injecting pumps may be employed to work four oil presses with the same facility as two; but in this case two Presses should be in action at once, whilst the others are recharging. In order to allow for a small horizontal movement, which may take place by the alternate expansion and contraction of the wrought iron bars C C, from the strain applied in pressing, and which causes a liability to fracture the copper pipes leading from the stop and discharge valves to the cylinders, it is found necessary to make them of a curved form, as shown in the figure.

The general operation of the mill is as follows: the seed is in the first place bruised or broken between iron rollers, in the same manner as in the common mills, after which it is submitted to the first operation of the Press. The cake is then removed and passed under vertical runners until sufficiently reduced, when it is

Manufactures.

warmed in pans and again submitted to the Press. The first pressing is effected as speedily as possible, generally in about six minutes, but in the second more time is allowed.

There are employed altogether in this mill, which contains two Presses, three men and one boy; one of the men has the charge of warming the seeds in the pans and filling the bags; another takes care of the pressing; the boy takes the cakes out of the bags, trims them, and puts the bags into their proper places; and the other man has the management of grinding the cakes after the first pressing under the vertical runners.

Comparative effect of different presses.

(511.) In the way represented above, there was pressed, in the beginning of the year 1822, from five o'clock in the morning to seven at night, amounting to a day's work of 12 hours, allowing for stoppages, half a Bremen last, or from 2000 to 2020 pounds of seeds; but they afterwards increased the quantity, when better acquainted with the action of the Machine, to $4\frac{3}{4}$ lasts per week, which is equal to from 2667 to 2693 pounds per day. The product of oil got from a last of seed, varied with the quality of the seed from 1300 to 1600 pounds; about 1500 pounds is considered to be the average quantity; of this about 1250 pounds are obtained the first pressing, and 300 pounds the second.

Several comparative trials with the same seeds have been made with Mr. Plump's mill, and a fine Dutch mill worked by Dutchmen at Bremen, and the results have proved in favour of the former.

A comparison was also made between the daily produce of Mr. Plump's Presses, and that performed by stampers at a large mill belonging to Michael Shepley, Esq. at Carshalton in Surrey, where the regular work of three men at the stampers amounts to seven quarters, two bushels of seeds, or 58 bushels per day, and that 47 pounds is the full average weight per bushel of good seed.

Mr. Plump's Presses produced, as before stated, from 2667 to 2693 pounds Bremen weight, or $\frac{2667 + 2693}{2} =$

2680 pounds Bremen on the average. The ratio of the Bremen pound to that of the English is as 100 to 109.8, as appears from Dr. Kelly's *Universal Cambist*, so that

2680 pounds Bremen weight will be $\frac{2680 \times 109.8}{2} =$

2942.64 pounds English. This quantity divided by 47, the average weight in pounds of a bushel of seed, will be 62.6 bushels, from which it appears that the effect of the hydro-mechanical Presses is not inferior to that of the ordinary method by stampers.

The hydrostatic press mills are said to possess these advantages over the ordinary method: that no peculiar locality for the erection is necessary; and that the space required for each Press is much less than that which would be occupied by a sufficient number of stampers to contain a like quantity of seed, particularly as the principle of the communication with the pumps admits of Presses being placed at any distance from, and in any direction to, the position of the first mover, which a peculiarity of situation may demand. The hairs and bags are also found to last much longer than those used in the stamper presses.

Mill for cocoa nut oil.

(512.) These advantages, it appears, are now generally acknowledged, as within a few years several mills have been constructed on this principle. The Bramah Press is

also used for extracting the oil from cocoa nuts with equal success, and a great many have been exported to Ceylon and other parts for the purpose. Machinery.

The cocoa nuts are first ground under runners or edge-stones into the state of pulp, which is put into hair bags, and submitted to pressure. The Presses are made to act vertically, and the bags are placed between horizontal plates so as to fill the space between the follower and the top of the frame. When the pressure is applied, the oil makes its escape through the bags and runs over the edges of the plate down to the follower, on the upper side of which channels are made to conduct the oil to an aperture connected with the copper pipe, which conveys it to the reservoir. The copper pipe, which of course ascends and descends with the piston, is made to slide in another large tube, so that the communication with the reservoir is perfect, whatever may be the elevation of the follower.

These Presses are constructed with two injection pumps, of one and two inches diameter, in order that a greater power may be applied at the completion of the action of the Press, when the resistance becomes greater. The levers which work the pumps are also made to shift, so that several degrees of power may be produced, as the state of the nut may require. In a Press which was constructed by Messrs. Bramah, under the direction of Thomas Hallyn, Esq., for the Island of Ceylon, the piston was eight inches diameter, and injection pumps one and two inches. The areas of the Press and two injection pumps are as the squares of their diameter in one case, viz. as 4:64, or as 1:16, and in the other, with the smaller injection pump, as 1:64: which constitutes the hydrostatic power of the Press. The mechanical power of the lever is as 1:10, when the pin or fulcrums are in the outer holes, and as 1:20 when in the others: so that by the multiplication of the ratios, the four hydro-mechanical powers will stand thus: $16 \times 10 = 160$ to $1:16 \times 20 = 320$ to $1:64 \times 10 = 640$ to $1:$ and $64 \times 20 = 1280$ to $1:$ which are in proportion to each other as 1.2.4.8. A man, whose weight is 150, will therefore be able to exert a force with this apparatus of 82 tons.

In using the Press, the action is commenced with the two-inch injection pump, the pin of its lever being in the outer hole, in order to save time. When the resistance has become greater than the power can overcome, the pin of the lever is fixed in the outer hole, and the action continued; when, however, this power is insufficient to overcome the resistance, recourse must be had to the one-inch injection pump with the pin of the lever in the outer hole, and finally the utmost power of the Press exerted, by shifting it to the inner hole.

The oil thus obtained from the cocoa nut, when it arrives in this Country, is in a white congealed state, at the usual temperature of the atmosphere. It is employed for various purposes where oil or fat is required, but more particularly as a substitute for oil in lamps, as it is considerably cheaper, and burns with a clear bright flame. In using it in lamps in the state in which it arrives in this Country, it is necessary to render it previously liquid, its own combustion will then generate a sufficient portion of heat to allow of the capillary attraction going on without any further trouble, if the lamp is constructed so that the reservoir of oil is sufficiently near the burner. This difficulty in its application as oil has been overcome by an improved process of refining it, for which a patent was taken out in 1831. It consists in separating by

Manufactures. extreme pressure the fluid part or oil from the solid part ; by this means not only the oil is so improved as to be fit to burn in any lamp, but the residue is sufficiently solid to make very good candles. It burns with as good a light as spermaceti, and is very much cheaper, so that its use is now becoming very general, as may be judged from the greater quantity imported in this Country in the year 1832 than in 1831, which is about the time the invention came into notice : the former amounting to 10,808, and the latter 4,328.

(513.) *An Account of the Quantities of Olive and Palm Oil imported into and exported from the United Kingdom, and cleared for Consumption, the Rates of Duty, and the Net Revenue thereon in each Year, commencing 5th January, from 1820 to 1831, both inclusive.*

OLIVE OIL.					
Years	Imported.	Exported	Cleared for consumption.	Rates of duty per Imperial Gallon.	Net Revenue.
	Imp. Gal.	Imp. Gal.	Imp. Gal.	s. d.	£.
1820	499,289	54,946	502,058	1 6	37,194
1821	634,766	47,437	597,602	..	44,404
1822	920,812	21,879	796,306	..	58,850
1823	869,770	189,297	679,949	..	49,957
1824	880,637	54,758	889,429	..	66,257
1825	1,581,074	76,720	1,007,225	0 8	44,161
1826	724,719	235,710	850,982	..	28,327
1827	1,028,174	132,680	1,070,765	..	35,767
1828	2,336,001	117,965	1,753,338	8d. and in ships of Naples or Sicily 9d.	58,471
1829	1,153,835	187,501	1,334,758	8d. and in ships of Naples or Sicily 10d.	45,155
1830	2,791,057	221,028	2,147,876	..	71,780
1831	4,158,917	672,852	1,928,892	..	64,243

PALM OIL.					
Years.	Imported.	Exported.	Cleared for consumption.	Rates of duty per Cwt.	Net Revenue.
	Cwts.	Cwts.	Cwts.	s. d.	£.
1820	17,456	423	41,745	2 6	5,100
1821	102,490	455	98,219	..	11,225
1822	63,898	803	67,539	..	8,417
1823	66,573	471	72,345	..	9,043
1824	74,410	479	74,523	..	9,287
1825	85,456	1,221	84,983	..	10,623
1826	99,068	2,349	94,268	..	11,782
1827	94,296	2,117	98,070	..	12,240
1828	126,553	5,247	120,599	..	15,075
1829	179,946	4,751	175,394	..	21,924
1830	213,477	15,302	179,652	..	28,428
1831	164,760	2,552	175,452	..	21,933

Rolling and Hammer Mills.

Rolling and forge mills. (514.) The terms rolling and hammer mills have been given to the Machinery employed in the reduction and manufacture of iron and other metals, although the operation in which they are employed differs entirely from that to which the term mill was originally applied, and intended to signify. The rolling-mill consists of two cylindrical rollers of iron or steel, which are put in motion by a water-mill or steam engine, and are so moved that they cannot recede from each other ; so that when the iron is placed red-hot between them it is drawn in by the revolution of the Machinery, and reduced to a thickness equal to the space between the surface of the rollers.

Machinery. The hammer-mill consists simply of a large hammer, raised by the power of Machinery, by which a greater blow can be given than by manual labour.

The use of these mills in the manufacture of iron is very important : first, by depriving the iron of the carbon which is combined with it when in the shape of cast iron, to render it malleable ; and, secondly, by reducing it into bars of any figure that may be convenient for the purposes to which it is intended to be applied.

Fig. 1 and 2, pl. xli. is a front and side elevation of a rolling-mill for making flat bars. A A A A are strong cast iron frames, resting upon iron bars *a a*, in the masonry to which they are secured by strong bolts *b b*. The masonry B B rests upon the foundation of the mill, which is required to be very secure : where the ground is bad it is necessary that the brickwork should be carried down ten or twelve feet, and in some cases piles are driven. C C are two other frames, which give support to the pinions P P, by which the motion is conveyed from one roller to the other : they have a bearing on the iron plate *a a*, and are securely bolted to the masonry. R R R' R' are the rollers ; the lower one of which receives motion from the engine, and communicates it by the pinions P P to the upper one, which is thus turned in the opposite direction.

D D are couplings, which unite the pinion shaft to that of the rollers, in such a manner as to allow an elevation or depression of the upper roller, so that the rollers may be adjusted to the required dimensions of the bars without affecting the action of the Machinery. In iron Manufactures this adjustment is not generally required, as the bars are all made to given dimensions, which are not commonly deviated from. In this case the pinions do not require to be placed in another frame, but are situated on the roller shafts at the outside of the frames. When the adjustment required is very small it is commonly done with the pinions on the roller shafts, in which case the pinions are required to have large and long teeth, so that a slight alteration in the pitch line will not sensibly affect their action. This method is, however, attended with an extreme liability to break the teeth when in shallow gear, from the immense blows to which they are subject when the iron is first applied.

The cast iron frames A A are grooved inside, so as to admit of other frames being moved up and down in them. One of these is seen at E E, fig. 2. F F F are screws which work in the head of the cast iron frames, by means of which the sliding part E E can be lowered or raised, and at the same time the upper roller. Some means are required in large mills, to keep the rollers in the proper position after being adjusted, otherwise by their own weight they would remain resting upon the lower roller.

This is effected in the mill represented in the drawing, by weights W W, suspended to a lever, at the other end of which are attached vertical rods *r r*, which pass up through the framework of the Machine to the lower brass of the rollers : they are thus pressed with a force or weight greater than that of the rollers, and consequently, should the adjusting screws F F be elevated, the upper roller will follow, and the space between the rollers will indicate the dimensions of the bar to be rolled. Another very important reason for causing the rollers to follow the adjusting screws is, that if they remain resting on the lower one when the iron is introduced they are thrown up with such tremendous force against the upper bearing as to endanger the breaking of the

Manufac-
tures.

Machinery, and even of the rollers themselves, which is an accident that sometimes happens even with the greatest caution, in consequence of the enormous power which is required to put in motion this kind of Machinery.

Rollers are usually made of cast iron, and are very exactly turned on their surfaces, and also in their necks, that they may work perfectly true when put in their places. The most common way of turning them is, first to mount the roller in a strong turning lathe, by holes or centre-points made in the ends, and by that means to turn the two necks truly cylindrical; afterwards to put the roller in its proper place in the rolling frame, and placing brasses over the necks; they then are held down by blocks fitted under the pieces which retain the gudgeons of the upper roller, and in this situation the mill is put in motion, and a bar of iron being fixed up for a rest, the surface of the roller is turned true, in the same manner as if it were in a lathe, with this advantage, that it is certain to be exact, being formed from the same bearing on which it is afterwards intended to work.

Casting
rollers.

(515.) In casting a roller, the mould should always be placed at a considerable depth beneath the orifice where the metal is poured in, so that the pressure of a column of fluid metal may be obtained to consolidate the casting, and render it free from those air-holes or porous places which will sometimes occur in metal cast in the ordinary way. The long piece of metal which filled the aperture through which the metal ran, and which composed the column above alluded to, is left adhering to the roller, and is cut off afterwards. Casehardened rollers must be used when it is required to have a very fair surface, *viz.* for such purposes as rolling iron, to make thin plates for tinning: also the large rollers for gold and silver, such as are now used in the Royal Mint: rollers for making tinfoil, steel plate for saws, and for many other purposes. Cast iron rollers are not hardened by a subsequent process, as in casehardening wrought iron, but are cast in that state by employing iron moulds.

A cast iron cylinder of three inches thick, and its diameter equal to that of the roller, is bored out with great accuracy, and fitted with ends proper to form moulds for the necks required at each end of the roller. It is buried in the sand of the foundry, and when the metal is run into it, the rapid transmission of heat through the iron mould causes the metal in contact with it to cool sooner than the other parts of the mass, which has the effect of rendering the surface of the roller very hard. In turning a roller of this kind the centres must be chosen so that the circumference turns as true as it will admit of, and then a very small quantity being taken off will render it perfect. This care should be taken for two reasons: first, that less will require to be removed to make it true, which is important, from the difficulty of getting tools sufficiently hard to touch it; and, secondly, that if the metal be unequally reduced, or more on one side than the other, the hardest part will then be cut away, and the roller will have a hard and a soft side, and will in consequence soon wear out of the circular figure, and require a second turning. The less metal there is turned off a casehardened roller the better, because the hard part is only a case of little thickness, and most hard at the surface.

Operation
of rolling.

(516.) The operation of the rolling-mill is so simple as scarcely to require any description. The metal is heated in a reverberating furnace, when it is in large masses;

and for smaller pieces a kind of oven is used, in which the coke is laid on the bottom or floor of the oven, without any grate bars, and the draught of air being by this means less rapid, it gives a slight and very regular heat, and therefore does not waste the iron by burning it to scales, as a great heat and current of air will do. This oven is proper for heating plates, hoops, or small bars, to be rolled a second and third time; but for rolling large masses a stronger heat is required that the metal may be consolidated, and all flaws or cracks securely closed.

Machinery.

The iron being heated in the furnace to the proper degree for the purpose which is intended, it is presented to the rollers, which are previously adjusted to the thickness of the piece to be rolled. If this is not attended to, and the workmen attempt to reduce the iron too much at one time, there is danger of breaking some part of the Machinery, or stopping the mill whilst the iron is only half passed through, which is a very disagreeable accident, as it requires a considerable power applied to the screws to turn them back sufficiently to relieve the rollers.

When the iron is placed on the shelf S in front of the rollers, their motion will draw it through, and as they cannot recede from each other the metal is reduced to the exact thickness of the space between them, increasing in length, but not at all in breadth: the iron is caught by another workman behind the rollers, and returned over the top roller to the first man, who passes it through the next opening of the rollers; it is again returned to the first workman, and the operation is thus continued until it is reduced to the required shape and dimensions.

Fly wheels are more required in rolling-mills than in almost any other kind of Machinery, because the resistance to be overcome is so variable, being at one moment very great for a large piece of iron, then smaller whilst it is passing through a second time, because then it is to be less reduced; and in the interval of returning the iron there is no other resistance than that of the friction of the Machinery. Again, when the iron has been passed through several times, the resistance is greatest of all, because the metal has become harder, both by the compression it has undergone, and from being gradually cooled; also the metal being thinner will not yield so readily to the pressure as when in a larger mass.

In order to increase the momentum of the fly wheel it is usually put upon a distinct shaft to that of the lower roller, and receives motion from it by cog wheels, and is thus made to revolve with great rapidity.

(517.) *Rolling iron plates.*—Iron plates, when of considerable size, such as those used for steam engine boilers, tanks, or other large vessels of wrought iron, are rolled from blooms or half-blooms, made under the forge hammer. The blooms are nearly of the length of the intended plate, their breadth about one-half or one-third as much as their length, and of a thickness to contain as much metal as will make two, three, or four plates. These pieces, when heated to a white heat, are presented breadthwise to the rollers, and passed through several times at the same heat, until the breadth of the bloom being extended two or three times becomes equal to its length. The thick, square plate thus formed is now cut up by shears across into two or three pieces of about the same size as the first, but in a direction which will make what was the length of the first piece to be the breadth of the second. These pieces being heated and rolled again become extended to the size of the required plates:

Rolling iron
plates.

Manufac-
tures.

the reason of thus dividing the operation is, that the rolling only extends the metal in the direction in which the rollers move, and not at all in breadth: but by this means the particles of iron being drawn by the sides of one another, acquire in a degree a fibrous texture, which is desirable in bars, rods, hoops, &c., but not at all in plate, as this should be equally strong in either direction; therefore by rolling it first one way and then the other, the grain, as far as it is produced at all, is in both directions. There is no doubt that better plate would be made if the slabs or original pieces were cut to the proper proportion of length, breadth, and thickness to form only one piece: then rolling it alternately length and breadthwise every time it is passed between the rollers, and continuing thus until the plate is finished, a better grain or texture would be acquired, because by the former method it will be weaker one way, in consequence of the grain produced by the last rolling.

Plate
rollers.
Pl. xli.
Fig. 3, 4.

(518.) In fig. 3 and 4 is given a side and front elevation of a pair of plate rollers. R R R' R' are the rollers, which are made of cast iron, casehardened, and are turned perfectly true in their bearings. As the adjustment of plate rollers is not generally required to be of great extent, the pinions P P, which communicate motion from one to the other, are placed upon the roller shafts. The adjustment is effected by screws S S, to elevate or depress the frames F F, which carry the brasses of the upper roller. When the rollers are in use, a spanner is placed upon each of the nuts of the screws, and after the iron is passed once through the mill, the workman who stands in front to introduce the metal, turns the nut which is nearest to him on his left-hand side, whilst his mate, who receives it and hands it back again to him over the roller, turns the nut on the opposite corner of the same frame. The workman in again passing it through gives the nut another slight turn, and the operation is thus continued until the plate is reduced to the required thickness.

Iron plates which are employed for tinning require to be of the best English iron, and some of the thinnest are made from foreign iron. The original bars are drawn out by the forge hammer into bars five inches broad and half an inch thick, which are cut into lengths of eleven inches, by shears. These pieces are then heated in an oven, and passed breadthwise through casehardened rollers, which operation is repeated until they are extended to twice the length of the intended plates; the pieces are then folded, and set on their edge in the furnace till properly heated, when they are rolled double, the fold being put in first; they are thus extended to twice the length of the intended plates.

Two men with strong tongs now tear the two leaves asunder at the fold, and fold each again, separately putting one into the other, like two sheets of paper. In this state they are heated and rolled four thicknesses together, the next time eight, and so on, until the plate is reduced to the required thickness. In manufacturing the thinnest kind of plate, such as that used for tagging laces, sixteen leaves are rolled together. In folding the plates, care is taken every time to put a new surface of metal outside, otherwise those which are constantly reduced by the pressure of the adjacent leaves, would at length become grained on the surface; but by continually gaining new surfaces, which are smoothed by the immediate tact of the rollers, those which are laid against them are also rendered smooth. A small quantity of oil is sprinkled between the leaves when they are first put in,

which instantly spreads over the whole surface and prevents any adhesion; the plates are squared by the shears every time before they are folded, to remove those parts which, by projecting over the edges of the other leaves, are not so much reduced.

After being finished, dressed square, and the surface scoured, the plates are rolled singly, between a pair of casehardened rollers without being heated; they are by this operation extended but little in size, although rendered much harder and less flexible.

(519.) Mr. William Daniell of Abercarne, Monmouthshire, took out a patent in the year 1822, for an improvement in rolling iron plates for tinning, which consisted in rolling the iron perpendicularly between rollers with grooves of different gradations. The iron is cut by a pair of shears into pieces of four inches and a half square, and passed singly through the first groove of the rollers, it is then passed through the second, and so on successively until it is reduced to a proper thickness for the manufacture of the plate. By means of rolling the iron perpendicularly, the inventor states that the inside of the piece of iron is brought to the surface, and any imperfection which it contains, instead of being dispersed and intermixed throughout, is forced to the edge and ends. The quality of the iron for tin plates, he states to be thus much improved, and the number of tin plate wasters thereby reduced.

Machinery

Daniell's
patent
rollers.

(520.) In rolling and slitting iron for nail rods or small hoops, the iron is brought from the forge hammer in bars of a size proportionate to the nail rod intended to be made; these are cut into length by shears, heated in a furnace, and repeatedly passed through rollers until they become the thickness of the square of the intended rod. In this state it is presented to the slitters, which are rollers resembling in shape the right-hand part of the rollers in fig. 1; each of the openings is of a width equal to the thickness of the rod, and the corresponding ring of the other roller projects some distance within the opening, as seen in the figure; by this means when one of the bars above mentioned is introduced between the guide bars of the slitters, the ring of one roller presses a corresponding breadth of hot metal into the space between the rings of the other; this being performed in the same manner by both, completely divides the bar into several rods of the same breadth with the rings of the rollers. A small leaden pipe is fixed over the cutters, which, being perforated with holes, constantly lets fall a supply of cold water upon the rollers to prevent them from becoming hot, and thus losing their hardness, which alone preserves their figures under the intense pressure they have to sustain in dividing the iron. This apparatus for cooling the rollers is common in most rolling mills, to prevent the ill effect which would result from their getting hot; and guide bars also are placed near the rollers to force the rods when cut out of the grooves between the rings of the collar, which they would not otherwise quit after being so forcibly pressed into them by the rings of the opposite roller. In making small hoops, the rods, as soon as they are formed, are put through the plane rolls again and flattened into a hoop.

Rolling iron
for nails,
hoops, &c.

In the country, iron hoops are made from bars reduced in rollers which are cut into lengths, heated and passed through slitters which divide them into three or four rods; they are then immediately presented to the casehardened rollers and flattened into hoop iron. In London, where a vast quantity of old hoops can be procured, they are remanufactured, and make the best

Manufac-
tures.

description of hoops. The Victualling Board alone consumes many hundred tons annually for the service of the navy. The old hoops are made up into faggots, and shingled or welded into a bloom at one heat by a forge hammer. The blooms being again heated, are rolled out into bars and cut into two or three lengths, according to the sizes of the intended hoops; these pieces are heated a third time, slit into rods as above described, and then formed into hoops by casehardened rollers. By successive improvements, it has been found that two heats are sufficient, the first for shingling and forming the bars, and the second for slitting and flattening the hoops. Vat hoops or others about two inches in width do not require to be slit, but are at once carried from the bar rollers to the plain rollers which finish them. The piles for shingling must not be made too large or the hoops will not retain sufficient heat to be sound; about forty-two pounds is a proper quantity. The mill for this manufacture must of course have great power, and the rollers should move with sufficient velocity to enable the iron to be got through while sufficiently hot.

In rolling iron for nails, one of the rollers is made with teeth on its surface resembling a ratchet wheel, which divides the rod into pieces of the length and shape of the intended nail, the size and shape of the latter depending on the description of teeth upon the surface of the roller.

Rolling
brass, cop-
per, &c.

(521.) The rolling-mill is not confined to the laminating of iron, but is likewise employed very extensively for reducing brass, copper, tin, lead, as well as gold and silver. The latter metals are scarcely reduced by any other means than rolling, as this method makes no waste, is more expeditious, and produces better work than hammering or any other method, particularly when an equality of thickness and even surface is required, as in the case of gold and silver. In this description of work the rollers are made of steel hardened and polished on the surface with the greatest nicety, that they may produce a perfect surface on the metals which have to be passed through them.

Hammer-
mills.

(522.) *Hammer-mills* are commonly used in the conversion of cast iron into malleable iron. The cast iron after being decarbonized in a reverberating furnace, becomes a mass of grains of about the size of a mustard seed, which have very little adhesion for each other, and is full of interstices. The use of the hammer-mill is to beat these grains into one mass, which is done at a welding heat. Hammer-mills are also employed in forging the heavier description of iron work, such as anchors. They are of two kinds, termed the lift hammer, and the tilt hammer; the former of which is supported at the extremity and raised by a wheel underneath, and the latter is supported at about one-third of its length, and is elevated by a wheel above, which acts upon the part of the shank extending beyond the point of support.

Fig. 5, 6.

In fig. 5, 6 of the plate are given elevations of a lift and tilt hammer. A A A, fig. 6, is one cheek of a framework which is strongly secured to the masonry of the foundations, and to a similar cheek on the opposite side of the hammer by bolts, *a a a*, &c, and thus forms a firm bed for the plumber blocks B, C. S S is the shaft of the hammer which is made of timber secured by wrought iron rings *b b b*; this is fitted into a cast iron socket D, with trunnions or axles cast upon it, which turn in brasses in the plumber blocks C. E is the wheel by which the hammer is elevated; it is cast with ears or tappets *c c c* upon it, which during the re-

volution of the wheel engage the end of the shaft, and continue to depress it until, by the continuation of the motion, it is disengaged, and the hammer head falls with considerable force upon the anvil. By this means a repetition of blows is kept up, which are of course much more effective than can be accomplished by manual labour.

When a very heavy blow is required, the most convenient construction is the lift hammer, shown in fig. 5. Here, A B is the hammer, which is composed of a solid mass of cast iron, weighing from three to four or five tons. At the extremity, A, are two pieces cast, running at right angles to the shaft of the hammer, which cause it to resemble, when viewed from above, the shape of a T; the end of one of these pieces is seen at C in the figure; it has, at the lower part, a circular projection, which rests, in a corresponding indentation in the framework D D, and serves for the support on which the hammer turns. In consequence of a liability of the end of the hammer to spring up after a blow is struck, a wrought iron band or strap is passed over a projecting part on the end of the hammer and over a similar one on the framework, which prevents any such effect taking place. The elevation of the hammer is effected by the wheel W, by the shape of which it will be seen that the hammer will be raised three times during one revolution of the shaft. The part *c c* which engages the wheel is not cast upon the hammer, for being liable to wear from the constant friction of the wheel, it is made in a separate piece, which is attached to the hammer by bolts and nuts, and can thus be readily shifted and replaced when required. The surface of the wheel which comes in contact with this piece, is composed of steel, let in and secured to it by wedges and keys.

In hammer-mills, as well as rolling-mills, the use of the fly wheel is much required in consequence of the variability of the power which is exerted upon them. It is very common with tilt hammers, in consequence of the suddenness with which they come into action, to connect the parts of the fly wheel shaft by a wooden spring coupling, which takes off the shocks that would otherwise be brought upon the engine.

Foundations for hammer-mills require great attention, otherwise the repeated blows of the hammers would cause the anvils to settle. To remedy this, the foundation of the frame is carried down ten or twelve feet into the ground, so as to form a heavy mass of masonry, and the anvil rests upon a large wooden pillar, strongly secured by wrought iron rings; this is supported and forms part of the masonry above alluded to, so that no settling can take place without the whole mass being moved together.

Within a few years it has been discovered that the process in which the hammer-mill is employed, *viz.* that of uniting the particles when separated in the puddling process, can be performed efficiently by rollers, and the hammer-mill has in consequence been done away with in some very extensive iron manufactories. This fact was first discovered by the late Mr. Wilkinson, who employed in his extensive works at Brosely, in Shropshire, a pair of enormous rollers, to which a reciprocating motion was given by a steam engine; they were five feet in diameter, nearly ten feet long, and weighed nearly five tons, although cast hollow like garden rollers; sectors were fixed on the ends of the gudgeons, by which one roller turned the other about one-third of a revolution, and then moved back again. The circumference of the

Machinery

Manufac-
tures.

rollers were cast with grooves gradually diminishing from one end to the other. The mass of iron to be rolled was collected into a ball in the furnace, which was taken out and passed through the greatest of the grooves. When it came through, a workman at the opposite side removed the ball to the next smallest groove, which by the returning motion was carried back to the front; the front workman then returned it in another groove, and so on, passing it successively through the different grooves, until by gradual consolidation it was reduced to an imperfect bar of malleable iron. A number of these being cut into lengths, were made up into faggots or piles, and by a pair of rotating rollers were finished into bars. Mr. Wilkinson had a patent for this Machine, but it was afterwards found that common rollers would effect the object better. The rollers now used for the purpose do not differ much from those shown in fig. 2 in the plate, except that the number of grooves is much greater, and that the larger ones, where the metal is first put in, are made of a circular figure, with teeth at several places on the circumference by which the metal is more readily drawn in. The use of these rollers is very similar to those we have described above, the ball of metal is taken from the furnace and passed through them ten or twelve times, being passed through a smaller groove each time, so as to compress it in a greater degree every time till it is at last reduced to a square bar. The last groove has also teeth in different parts of the circumference, and at such dimensions and distances from each other, that they will indent so deeply upon the angles of the bars at every eight or ten inches of their length, as to render it easy to break them into short pieces when they come through. The pieces thus formed are piled four or more together and put into a balling furnace, and when heated are rolled into thin parallel bars, in which state they are usually sent to market.

The rollers are said to enclose the impurities of the iron rather than to expel them; but as rollers require much less power to give them motion than the hammer, it becomes worth the consideration of manufacturers to improve their construction and render them equal in effect to the hammer.

Saw-mills.

Saw-mills.

(523.) Saw-mills are of recent introduction in this Country, although they have been employed many years on the Continent. Their history, with that of the invention of the saw, is given at considerable length by Beckmann, in his *History of Inventions*, from which we quote those parts that appear most interesting.

In early periods of Society, the trunks of trees were split with wedges into as many and as thin pieces as possible; and if it was necessary to have them still thinner, they were hewn by some sharp instrument on both sides to the proper size. This simple but wasteful manner of making boards, has still been continued in some places to the present time. Peter the Great of Russia endeavoured to put a stop to it by forbidding hewn deals to be transported to the river Neva. The wood splitters perform their work more expeditiously than sawyers, and split timber is certainly much stronger than that which has been sawn; because the fissure follows the grain of the wood, and leaves it whole; whereas the saw, which proceeds in the line chalked out for it, divides the fibres, and by that means lessens its cohesion and

VOL. VII.

strength. Split timber, indeed, turns out often crooked and warped; but in many cases to which it is applied, this is by no means prejudicial, and the fault may sometimes be amended.

(524.) The inventor of the common saw has, by the Greeks, been inserted in their Mythology, and placed among those whom they have honoured as the greatest benefactors of the earliest Ages. By some he is called Talus, and by others Perdix: Pliny ascribes the invention to Dædalus; but Hardouin, commenting on the passage in which it is mentioned, considers Talus rather than Dædalus as the inventor. Diodorus Siculus, Apollodorus, and others, name the inventor Talus. He was son of a sister of Dædalus, and was placed by his mother under the tuition of her brother to be instructed in his Art. Having, it is said, once found the jawbone of a snake, he employed it to cut through a small piece of wood, and by this means was induced to form a like instrument of iron, viz. a saw: this invention, which greatly facilitates labour, excited the envy of his master, and instigated him to put Talus to death privately. We are told, that being asked, when he was burying the body, what he was depositing in the earth, he replied, "a serpent." This suspicious answer discovered the murder; and thus, adds the Historian, a snake was the cause of the invention, of the murder, and of its discovery.

The saws of the Grecian carpenters had the same form, and were made in the same manner as ours are at present. This is fully shown by a Painting which is still preserved among the antiquities of Herculaneum. Two Genii are represented at the end of a bench, which consists of a long table resting upon two four-footed stools. The piece of wood which is to be sawn through is secured by cramps. The saw with which the Genii are at work has a perfect resemblance to our frame saw; it consists of a square frame, having in the middle a blade, the teeth of which stand perpendicularly to the plane of the frame. The piece of wood to be sawn extends beyond the end of the bench, and one of the workmen appears standing and the other sitting upon the ground. The arms in which the blade is fastened have the same form given to them as at present. In the bench are seen holes, in which the cramps that hold the timber are placed; they are shaped like the figure 7, and the ends of them reach below the boards that form the top of the bench.

(525.) The first introduction of saw-mills seems to have been on the Roer, a river in Germany, in the IVth Century; for although Ausonius speaks of water-mills for cutting stone, and not timber, it cannot be doubted that these were invented later than mills for cutting out deals, or that both kinds were erected at the same time. Pliny conjectures that the mill for cutting stone was invented in Caria, at least he knew no building incrustated with marble of greater antiquity than the Palace of King Mausolus at Halicarnassus. This edifice is celebrated by Vitruvius for the beauty of its marble; and Pliny gives an account of the different kinds of sand used in cutting it: "for it is the sand," he says, "and not the saw which produces the effect." The latter presses down the former, and rubs it against the marble, and the coarser the sand is the longer will be the time required to polish the marble which has been cut by it. Notwithstanding these facts, there is no account in any of the Greek or Roman writers of any mill for sawing wood, and as the writers of more modern times speak of saw-mills as new and uncommon, it seems

Machinery.

Invention
of the saw.

First inven-
tion of saw-
mills.

Manufac-
tures.

either that the oldest construction of them has been lost, or that some important improvement has made them appear entirely new.

Saw-mills, although employed in many parts of the Continent as early as the XVth and XVIth Centuries, were violently opposed in England, under an idea that the sawyers would by the use of them be deprived of the means of subsistence. For this reason it was found necessary to abandon a saw-mill erected by a Dutchman near London in 1663; and in the year 1700, when a person of the name of Houghton laid before the nation the advantage of such a mill, he expressed his apprehension that it might excite the rage of the populace. What he dreaded was actually the case; for in 1767 or 1768 an opulent timber merchant, by the desire and approbation of the Society of Arts, having caused a saw-mill driven by wind to be erected at Limehouse, under the direction of James Hansfield, who had learned in Holland and Norway the art of constructing and managing Machines of that kind, a mob assembled, and pulled the mill to pieces; the damage, however, was made good by the County, and some of the rioters were punished. A new mill was afterwards erected, which was suffered to work without any molestation, and which led to the erection of others. It appears, however, that this was not the only mill of the kind then in Britain; for one driven by wind had been built at Leith in Scotland some years before. From this period, particularly since the improvements in the steam engine, the number of saw-mills has increased very rapidly, and they are now to be met with in almost every large timber merchant's yard.

Construc-
tion of
saws

(526.) *Construction of saws.*—Saws are constructed either of iron simply hammered and hardened, or of tempered steel ground bright and smooth. They are known to be well hammered by the stiff bending of the blade, and to be well and evenly ground by their bending equally in a bow. The edge in which the teeth are made is always thicker than the back, because the back has to follow the edge. The teeth are cut and sharpened with a triangular file, the blade of the saw being fixed in a whetting block, and after the teeth are filed, they are turned out of the right line, that they may make the kerf or fissure the wider, to enable the back of the saw to follow more readily. This is termed setting the teeth.

In sawing valuable timber the teeth are not turned out so much (or as the workmen term it, set so rank) as for coarse cheap stuff; because the ranker the teeth the more stuff is lost in the kerf. The saws used in cutting stone have no teeth; these are generally very large, and are stretched out and held evenly in a frame.

Pit saws.

Before saw-mills came into use the work was performed by two men with a saw, termed the pit saw, which is the one chiefly used in the employment denominated sawing. To perform the work, the timber is laid on two rollers over a rectangular pit, denominated the saw-pit; and the saw, which is of considerable length, with a cross handle at each end, is worked by the two men, one of whom stands on the timber to be cut, and the other in the pit. As they proceed with the work wedges are driven at proper distances from the saw to keep the fissure open, which gives more freedom to the motion of the saw. When they have advanced as far as the end of the pit the timber is moved forward on the rollers, which operation is repeated until the saw has arrived at the end of the timber.

Saw-mill.

(527.) *Saw-mill.*—The common saw-mill which is

generally employed in cutting timbers into planks, consists of a square wooden frame, in which a number of saws are stretched; this frame rises and falls in another wooden frame, secured to the foundation of the mill, in the same manner as a window-sash rises and falls, motion being given to it by a crank. The timber to be cut is placed upon a horizontal bed or carriage, sliding upon the floor of the mill, which being sufficiently narrow to pass through the inside of the vertical or moving saw frame, will carry the tree through and subject it to the action of the saw; the carriage is provided with a rack, which is engaged by the teeth of a pinion, and thus gives the means of advancing the carriage. The pinion is turned by means of a large ratchet wheel, with a click moved by levers connected with the saw frame; when the saw frame rises the click slips over a certain number of teeth of the ratchet wheel, and when it descends to make the cut, the click turns the ratchet wheel round, and advances the wood forward just as much as the saw cuts during its descent. The trees are generally dragged up an inclined plane, through a door at one end of the mill, and being placed upon the carriage, they pass through and are divided by the saw into two or more pieces, which are carried forward and passed out at a door on the opposite side of the mill.

Fig. 1 and 2, plate xlii. is an elevation of a saw-mill, constructed by Mr. Hague of Ratcliff for the Dutch Government, for the purpose of cutting planks, which is very ingenious and simple in its construction. A A A are timbers built securely in the foundation of the mill, to which the cast iron framework B B B is bolted by strong bolts and nuts at a a a a. This cast iron framework is a great improvement upon the wood framework hitherto employed, from its superior stiffness; and as the guides for the saw frames and other parts have to be attached to it, which are of iron, the liability of loosening, which always occurs when iron and timber are united, from the shrinking of the latter, is avoided. Motion is communicated to each Machine by leathern belts, very judiciously employed instead of cog wheels, because they will stop and yield if any thing should get foul in the movements, while toothed wheels would in a similar case break every thing to pieces. In fact, all Machinery, where the quantity of work is not constant, should be driven by belts in preference to cog wheels, for the reasons above stated. C C is a horizontal shaft, which has a bearing at each end in the sides of the framework. It has attached to it the fast and loose pulley D D, E E, which receives the motion from the steam engine when required, and a fly wheel F F F, of which one is necessary to every saw frame, independently of that employed at the engine. G G G G is the frame in which the saws are fixed; it is guided in its vertical motion by moving on square bars b b, attached to a projected part of the cast iron uprights or framing. This is a very excellent and simple method of guiding the motion of the saw frame, as it is attended with little friction, and any looseness that may take place from wear is immediately corrected by screwing up the nuts c c c c.

In some saw-mills friction rollers are employed for diminishing the friction between the saw frame and the channel it moves in, which are so placed that the frame is completely guided by them without rubbing against any thing else. They generally consist of four pair of rollers placed horizontally, all of equal diameter; each pair being connected by a common spindle, the length of which is determined by the breadth of the saw frame. The centres or bearings are fixed in such a

Machinery.

Pl. xlii.
Fig. 1, 2.
Saw-mill by
Hague.

Manufac-
tures.

manner as to admit of adjustment, in order to confine the saw frame to its true position, and give a steady motion. Similar rollers, to be applied at the sides of the frame, have also been proposed, but they appear to be attended with a liability to get out of order by wear, which gives an unsteady motion to the saw.

The saws are fixed and stretched in the frames by wedges, which are driven above through mortises in the upper part or bar of the saw. In this way any number of saws may be fixed on the frame, and at any distance from each other. It is, however, generally necessary, in consequence of a tendency which is given to twist the saw in the plane of its direction by tightening the wedges, to have pieces of wood of the exact thickness of the planking required placed between them, with similar pieces outside, which are all screwed firmly together by screws in the sides of the saw frame.

Mr. Brunel's method of fixing and tightening saws.

(528.) A very ingenious method of fixing and tightening the saws is employed in the saw-mills in the Royal Arsenal, Woolwich, invented by Mr. Brunel, who has devoted much time to the subject of saw-mills, and to whom we are indebted for many important improvements. By his method a number of saws can be very speedily removed, and a new set of sharpened ones put in. Each saw has pieces of metal rivetted to it at each end, which are formed like hooks. The hook at the lower end of the saw falls into a proper recess made in the lower cross bar of the frame, and the upper hook is engaged with the hook of a shackle or link, which hangs upon the upper cross bar, and has wedges through it, by means of which it can be drawn tight to strain the saw. As the tension of the different saws is in some measure uncertain, when merely depending upon driving the wedges of the shackles by a hammer, Mr. Brunel has employed a very ingenious steelyard, which not only shortens the time required for wedging them up, but exhibits the degree of tension which is given to the saw. It consists of the following parts. A strong axle is extended across the fixed frame, in which the saw frame slides, and above the top of this frame, from one side of this axle, a lever proceeds, which has a weight fixed at the end, and from the opposite side of the axle proceeds two short levers, which are connected by links with a strong cross bar, situated just over the upper cross bar of the saw frame, when it is at its greatest point of elevation. This cross bar of the steelyard has a link or shackle upon it, which can be united by a key with any of the shackles upon the upper cross bar of the saw frame, which shackles are as before mentioned united by the hooks with the upper end of their respective saws; and by this means the lever with its weight becomes a steelyard to draw up any one of the saws with a determinate force. In using this apparatus the band or strap of the crank shaft is cast off to stop the motion of the saw frame, the crank is turned round to elevate the frame to the highest point; two wedges are then put in between the saw frame and a fixed part of the stationary frame, and this holds the saw frame fast while the steelyard is applied, otherwise it would tend to strain the crank and crank rod. The sharp saws are now put into the saw frame, by hooking them upon the lower cross bar, and uniting the hooks to the shackles on the upper cross bar, and pieces of wood are put between the saws according to the gauge of the wood which is intended to be sawn, and bound fast by screws, as has been described in the mill shown in the drawing. The loaded end of the steelyard is now lifted up by a rope passing over a pulley,

and the link upon the cross bar of the steelyard is united with the shackle of one of the saws; then by allowing the steelyard to descend, it stretches the saw, and the wedge being thrust in by the hand, as far as it will go, thus retains the saw at the tension to which the steelyard had stretched it. The shackle of the steelyard is then disengaged from the saw, and removed to the next, and thus in turn all the saws are strained more equally than can be effected by simple wedges.

Machinery.

Referring again to fig. 1 and 2. H H H is the section of the timbers composing the floor of the mill; I I I are cast uprights, which are bolted down firmly to the floor, and carry at their upper part horizontal rollers, upon which the timber is moved while passing through the mill. The timber is fastened at one end to a carriage attached to the rack seen at L, and at the other to a carriage which can be adjusted according to the length of the timber to be cut. M M is a rack by which the timber is moved on during the action of the saw, in the following manner. N N is a horizontal lever, which turns upon the point N, and receives a slight reciprocating motion from an eccentric *g* upon the crank shaft during the stroke of the saw, but in a reverse direction, so that while the saw descends, the end of the lever rises; *h* is a small arm attached to the lever in such a manner as to engage the teeth of a large ratchet wheel O O, while the motion is upwards, but in its descent simply passes over them without giving motion to the wheel. It has a small counterweight *n*, which causes the end of the arm to press gently against the teeth of the ratchet wheel *m*, in order that in its return it may not fail to engage them. It will then be readily seen, that during the descent of the saw, which is the time its action takes place, the lever N, by means of the eccentric, is moving the ratchet wheel round, from which, by a small pinion *p* upon its axle, which engages the teeth of the rack M M, the carriage and timber is moved gently forward towards the saw. The turning point of the lever N N can be adjusted to any part of it within the point *i*, where the eccentric rod is fastened, so that any degree of motion can be given to the timber according to the nature of the wood to be cut.

The part marked P P in the drawing is a guide for the timber while passing the saw frame, which causes the former to keep a direction parallel to the motion of the saw. The timber is pressed against the guide by means of a lever, (not shown in the drawing to prevent confusion,) one end of which is connected with a weight over a pulley, and the other to a roller, which is pressed by means of the weight against the timber, and keeps it in its proper position with respect to the saw.

When the timber has passed the saw, the carriage is returned by means of a handle *m* upon the spindle of the ratchet wheel and pinion, which is worked by a man; the click being of course thrown up clear of the teeth to allow of its motion in a reverse direction. In some mills this is effected by the engine; it, however, involves more Machinery than the necessity of the case requires, as a man can run it back in less than a minute.

(529.) *Circular saw-mills.*—The above is the description of mills generally employed for cutting timber longitudinally. Circular saw-mills are, however, sometimes used, and with considerable success, in cutting veneers. Mr. Brunel took out a patent in 1805 for improvements in the Machinery for sawing timber, in which he employed a large circular saw, composed of several pieces fitted together, by screwing them to a large flanch turned per-

Circular
saw-mills.

Manufac-
tures.

fectly true, which formed part of the axle of the saw; the holes through which the screws passed were cut in an oblong form, to admit of adjustment. When the plates have been thus fastened to the flanch, another detached flanch is laid upon the plates; and in order to make it fit and bear with equal force on each plate, several thicknesses of paper or leather of the size of the flanch are placed between it and the plates, and every thing screwed up tight by bolts and nuts.

The saw or saws, thus prepared, are placed in a frame at such an elevation that the bottom of their revolution is a little below the lower edge of the timber. The timber is placed in a carriage and moved towards the saw by a rack, in a similar manner to the common saw-mill.

Machine
for cutting
veneers
used in
Russia.

(530.) Circular saws of large dimensions are not commonly used in this Country, except for cutting veneers, which process is said to be performed in a much superior manner in Russia by a planing Machine. The construction of it is simple, combining the advantage of cutting the most valuable woods without waste, and very rapidly, to an extraordinary extent, and so thin that they have been employed for the covering of books, and for lithographic and other engraving. One hundred feet in length of veneering may be cut by this Machine in the space of three minutes.

The operation is begun by placing the timber from which the leaf is to be cut upon a square axle, when it is revolved and made circular by a turner's gouge. The blade of a plane of highly tempered steel, and rather longer than the cylinder, is fixed at the extremity of a frame of six or seven feet in length, in such a manner as to exert a constant pressure upon the cylinder, and pare off a sheet of an equal thickness, which folds upon another cylinder like a roll of linen. The frame to which the blade is attached is movable at its lower extremity, and as it is charged, it depresses in proportion as the mass diminishes in substance. That this depression may be progressive and perfectly regular, the inventor has appended a regulator to the Machine, consisting of a flat brass plate, preserved in an inclined direction, upon which the frame descends as the regulator itself is advanced. The motion is communicated to the cylinder by several cog wheels, which are turned by a crank.

Benchsaws.

(531.) *Bench saws.*—Although, as above mentioned, the circular saws of large dimensions are not commonly employed, the small circular bench saw is a most valuable instrument in large establishments, as in Government works. The saw is fixed upon an axle, and made to revolve by straps or bands with great rapidity. The wood being presented to it is cut by a continuous motion; and as this admits of far greater velocity than can be given to any reciprocating Machine, the circular saw cuts a surprising quantity of wood, not less from this circumstance than because it is always in action, whereas the reciprocating saw only cuts in one direction, and all the time occupied in the return is lost. These advantages, arising from the circular figure of the saw, are equally true whatever may be the diameter; but when the dimensions are large, several practical difficulties present themselves; such as the inconvenience of replacing a blunted or worn saw by a sharp saw, which of course must be more frequently repeated than in the reciprocating saw-mill, and other similar disadvantages, which greatly reduce their value.

The common bench circular saw is usually fixed in a horizontal table or bench, which has a cleft through which the saw comes up; the spindle being situated

under the bench, and across the direction of its length. Machinery
A segment or portion of the saw is left projecting above the bench, and the piece of wood being laid flat upon it is advanced forward to the saw, and cut with great facility, at the same time it is certain to be perfectly square; but if the sections are required to be at any other angle or bevel, the bench is inclined to suit it. A long parallel ruler is fixed down upon the bench, capable of being brought nearer to or further from the saw, and thus forms a guide against which the piece of wood is held; by this means the saw cuts always to the same width, but the width can be varied at pleasure.

The time of the introduction of this valuable Machine is not well ascertained. Circular saws for cutting the teeth of watch and clock wheels have been in use since the time of Dr. Hooke; but we do not know positively who first applied them to the sawing of wood: it is said to have been General Bentham who first introduced them into this Country. Mr. Taylor, of Southampton, used them in his manufactory many years ago; but it appears that Mr. George Smart, who has a manufactory on the Surrey side of Westminster bridge, was the first who employed them to any extent, since which time they have become very general for all kinds of purposes.

A great improvement in the method of mounting them was invented by the late Mr. Maudslay. The first saws were made with sharp conical points at each end of the spindle, which were received into conical holes in the ends of two screws fitted in the solid framework of the Machine; or the reverse, *viz.* the points were made upon the ends of the fixed screws, and the holes in the ends of the spindle; in either case both parts were made of hardened steel. But if this method is used on a large scale with a great velocity, the oil cannot be kept in the sockets, and the friction will then cause the points of contact to heat; by heating they expand, and thus increase the friction and the pressure, so that when once the effect of heating takes place it rapidly increases, until the metal becomes soft and will twist off the points. The conical form of the end of the spindle gives the oil a tendency to run up it, and thus escape from the point where it is chiefly wanted. This evil is avoided in the spindles proposed by Mr. Maudslay, which have double conical sockets: the oil is introduced by a small hole into the smallest part of the double cone where they join; by this means the centrifugal force draws the oil into the fitting, instead of throwing it out as in the common spindle.

(532.) *Sawing Machinery at Portsmouth.*—The most complete sawing Machinery in this Country is considered to be that used in the block Machinery at Portsmouth, also invented by Mr. Brunel, by which the timber is reduced from the tree to the proper sizes ready to be formed into blocks. The elm trees, of which the block is formed, is cut into proper lengths to form such blocks as the tree seems best adapted for, by two cross-cutting saws, one of which is a reciprocating and the other a circular saw.

The tree subjected to the action of the cross-cutting reciprocating saw is placed on a long frame or bench raised a little above the floor, on the end of which is erected a frame composed of vertical posts and a cross timber; through this frame the end of the tree is drawn by a capstan working in the middle of the room upon a vertical shaft turned by the steam engine. The end of the timber projects as much beyond the front of the frame as the part intended to be cut off, and is fastened from rolling sideways by a lever, which presses upon it and holds it down.

Sawing
Machinery
used in
Ports-
mouth
Dock-yard.

Manufactures.

Reciprocating cross-cutting saw.

The saw is a straight blade fixed into a wooden handle at each end to lengthen it; one of these handles is connected by a joint to the upper end of a lever, bent at right angles and having its centre beneath the floor; the horizontal arm of the lever is connected by a spear rod with the crank on the end of a spindle near the ceiling of the room, the motion of which is regulated by a fly wheel. By this means the saw has a reciprocating motion from right to left nearly in a horizontal position, and exactly across the log that is to be cut, resembling in its action the carpenter's handsaw. The teeth of the saw are of course on the lower side of the blade, and it acts entirely by its own weight. The Machine being at rest is prepared for work by fixing the log in the frame by the lever, so that the surface of the frame intersects the log at the place it is intended to be cross cut. The saw which was before lifted up by its handle to be clear of the log is now suffered to rest upon it in the place where the cut is to be made, and to guide it in first setting in, the back of the saw is received in a saw kerf made in the end of a piece of board, which is attached to the frame over the saw, but slides up and down to reach it at any height according to the thickness of the log. The Machinery is then put in gear, which causes the saw to reciprocate horizontally across the tree, and thus by its own weight cuts it through. As the saw gets into the tree it quits the guide above mentioned, which becomes less necessary as the saw goes deeper; a saw having no tendency to alter its course when cutting across the grain.

Circular cross-cutting saw.

(533.) The circular cross-cutting saw which is employed for the same purpose is more novel in its construction. The spindle is so mounted as to move in any direction parallel to itself, the saw continuing in the same plane; by this means it can be applied to any part, so that it will divide trees much larger than could otherwise be done by it. It is more expeditious and accurate in its performance than the one above described, for which reason the preference is always given to it in all cases where the size of the tree is not too great for its application.

Pl. xlii.
Fig. 3, 4.

Fig. 3 and 4. pl. xlii. is a plan and elevation of this Machine. A A is the tree intended to be sawn across; it lies upon a framing of timber B which supports it. Across the head of this frame a strong timber or ground sill C is framed, in which two uprights R S are erected; these with a cross beam at top form the frame which gives the means of confining the tree upon the bench while it is cut. The fixing of the tree is effected by means of a lever D, one end of which engages a bolt put in a hole in the post S of the frame to serve as a fulcrum, and the other end passes between the face of the post R, and a piece of wood *a*, which is bolted to it, and the lever being forced down upon the tree is kept down by a bolt put through a hole in the piece *a*, and also into the post. The other end of the lever is retained by a piece of wood similar to *a*, fixed to the post S; and by this means the tree is held steady while it is being sawn.

The roller, or capstan, T serves to advance the tree forward on the bench; it is turned by means of the handspike E, which has a small click engaging the teeth of a ratchet wheel *b*, fixed fast upon the axle or centre pin. The handspike being worked in the manner of a pump turns the roller about a few teeth of the wheel at every stroke, and by a rope wound on the

roller draws up the tree; it has a click *d*, which detains the teeth of the ratchet wheel, and prevents the roller running back after being moved by the handspike. The framing of wood, or bench, B is continued for some distance in front of the part S in order to form a support for the piece of timber which is cut off. It has a cross piece *f* bolted down to it which acts as a stop to the end of the tree; this piece is adjustable and serves to measure the quantity to be cut off; a space is left between the projected part F and the bench B, for the saw to descend into when it has divided the timber.

The saw, which is shown at G, is fixed on the end of a spindle *g* mounted in a frame consisting of two side beams H H, connected by cross pieces I I K L, and strengthened by diagonal bolts or ties *ee*; the upper cross piece is formed of iron, and its ends are jointed to the end of a frame M M, poised in the manner of a balance beam of a drawbridge, on a fulcrum supported by the fixed framing of the Machine, which consists of two posts N N, extending from the floor to the ceiling, and connected by a cross beam O O. By this means the saw can be moved in any direction at pleasure, but always preserves its parallelism. The saw receives its motion from the mill by the strap *h*, which passes over a pulley *i*, seen in fig. 3, contained in an opening in the iron top L of the frame H. It is fastened on a short spindle, which is exactly in a line with the joints connecting the two frames M M and H. Upon the same spindle is another pulley *k*, which gives motion by a strap to one on the spindle of the saw. Two small wheels *m m* are attached to the frame H to guide the strap, which can be adjusted, if necessary, in order to tighten it. *n n* are two pulleys which guide the main strap *h h*, which are placed near the centre of motion of the frame M M, in order that the tightness of the strap may not be materially affected by the alteration of the position of the saw. The workman governs the Machine by two winch handles V and W; the latter of these is on the end of an axle *w*, having two pinions upon it which engage racks on the end of two wooden rods Q Q. These rods are connected with the end of the great frame M M by the joint which connects the two frames together; so that by turning the winch W in one direction it elevates the saw, and in the other depresses it. In a similar manner, the winch V gives motion by a spindle *v*, upon which a pinion is attached which engages racks on the ends of two rods X X, jointed to the suspended frame H. Thus the position of the saw may be changed horizontally, or vertically, with respect to the timber. The two frames H and M are greatly strengthened by the rods Q Q and X X; for as these two pinions act equally upon the rods and thus move both sides of the frame alike, they preserve them from twisting, which would otherwise cause the saw to deviate from the parallelism. To produce this effect perfectly, it is, however, necessary that the pinions should fit the rack very accurately. Two rollers *y y* are fixed in a part of the same frame in which the spindle *v* has its bearing; they press upon the back of the rack, and keep it at all times in accurate contact with the pinion. A similar roller is applied at the back of the rods Q Q; by this means the teeth of the rack always engage those of the pinion, although they necessarily alter their direction at times by the change of position of the screw.

By this ingenious mechanism a circular saw will cut through a timber of nearly its own diameter, and with a rapidity that can never be attained by a reciprocating saw.

Machinery.

Manufactures.

cating motion: the saw when worn can be replaced by a new one, which practical defect being thus easily overcome, it possesses every advantage over the common reciprocating saw.

Other saws are employed in preparing the blocks, viz. a reciprocating saw for cutting up trees lengthwise, and circular sawing benches; these do not, however, differ from the mills we have described in the previous part of the article, and therefore do not require any further explanation.

In addition to the above sawing Machinery is that employed in preparing the *lignum vitæ* for the sheaves, which consists of two cross-cutting saws, one a reciprocating one, and the other a circular one. They do not differ in principle from those employed for the elm timber, although the hardness of the wood and different size of the timber require some alteration in the arrangement of the Machinery.

Reciprocating saw for cutting *lignum vitæ*.

(534.) The reciprocating saw is stretched in a wooden frame, which is necessary in consequence of the hardness of the wood requiring a much thinner blade and finer teeth than the elm.

The tree of *lignum vitæ* is placed horizontally, being held in a Machine which is similar to a large vice; it is opened and shut by two screws, both moved at the same time by cog wheels connecting them so as to move the jaws of the vice parallel. This Machine being used for cutting the ends of the trees into proper thicknesses for the sheaves, the vice which holds the tree is provided with a screw, which advances the whole together a proper quantity every time a sheave is cut off.

The vice is stationed upon proper sliders made truly parallel, in order that the pieces it cuts off may have parallel sides. This Machine is only used for converting the largest trees of *lignum vitæ*; the smaller trees are cut up by a circular saw, of very ingenious and curious construction.

Circular saw for cutting *lignum vitæ*.

(535.) It differs from the circular saw used for the elm, inasmuch as it can only be applied to the tree in one direction; but the tree is at the same time caused to revolve so as to present every part of its circumference to the action of the saw. The saw will therefore in this case also cut through a tree of nearly its own diameter. The construction is as follows.

The spindle of the circular saw is fitted in an iron frame which moves in a fixed vertical axis in the manner of a gate or door; its spindle being vertical the saw is of course horizontal, and its centre describes the arc of a circle when swung upon its centre of motion, but continues in the same plane. It is turned like the other Machines by an endless band which is conducted over pulleys, on an axle concentric with the axis of motion of the saw frame; by means of which the band has the same degree of tension at all positions of the saw: the vertical axle of the saw frame is supported by an iron standard, which is attached to vertical iron columns extending from the floor to the ceiling of the room. The tree of *lignum vitæ*, which is previously cut into lengths of two, or two and a half feet, is fixed in a chuck or clamp at the top of a vertical spindle, which is fitted in a socket in the middle of a cross bar sliding between two vertical columns. This cross bar is connected with another, which also slides up between two vertical columns, and they thus, together, form a large frame, which rises and falls by means of a screw working in a nut formed in the upper cross bar. The lower end of the screw rests on a step in the middle

of a fixed cross bar extending across from one column to the other, and perforated with two holes for the iron rods forming the two sides of the frame to pass through as they rise and fall. The chuck at the top of the spindle has two jaws by which it will hold trees of different dimensions, which are so contrived as to keep the tree at all times nearly central with the vertical axle. A rotary motion is communicated to the vertical spindle by a cog wheel fitted in a socket made in an iron plate, which is the base of the two columns. The lower end of the vertical spindle is made square, and moves up and down in a square hole in the centre of the wheel, and by this means the spindle continues to rotate whatever may be the elevation of the chuck.

When a piece of wood is required to be cut, it is fixed at the top of the vertical spindle, and raised by turning the great screw to such a height that the saw is opposite that part of the tree which is intended to be divided: the saw is in constant rotation from the mill and the workman presses it by a lever attached to the saw frame against the wood, which it cuts very rapidly. At the same time he turns the vertical spindle with the wood round by the winch, which operates on the cog wheel, so that all parts of the circumference of the tree are applied in succession to the action of the saw, which by this means will cut through a tree nearly twice its own radius, and in consequence of its revolution in a perfect plane, will cut off every piece of an equal thickness throughout. When the piece is thus separated, the workman swings the saw out of the way of the wood, and turns the screw by the cross handle, to raise up the frame with the spindle and tree the proper quantity to cut off such a thickness as will form the sheave intended. This quantity is measured by the screw, which has a ratchet wheel upon it with a click to prevent it from running back, which the weight of the iron frame and spindle would otherwise force it to do. The workman counts the number of teeth which pass the click as a measure of the proper elevation of the wood; in this way the operation proceeds with great rapidity, until the piece of timber is completely cut up, when the workman relieves the click, and the saw runs back and lets down the chuck ready to receive another length of tree.

For the above description of the saw-mills used in the manufacture of blocks, we are much indebted to Mr. Farey's description in Rees's *Cyclopædia*; but that account includes only those which are employed in cutting up the timber in proper sizes ready to be submitted to the block Machinery. We have, therefore, omitted here to describe the trepan, or crown saw, which is used to form the *lignum vitæ*, when cut into flat pieces by the Machine above described, into a circular figure, in order to form the pulley: this Machine belongs to the particular manufacture of blocks, and found described under that head.

(536.) *Saws for cutting piles under water.*—Foundations under water are generally formed in this Country by the use of a coffer dam, which consists of several rows of piles driven round the spot where the building is intended to be erected, with clay or other matter impervious to water filled in between them. The water may then be pumped out from the interior, which leaves the ground dry for the operations of building.

When the erection is completed, it of course becomes necessary to remove the coffer dam, which may be done either by drawing the piles or by cutting them off under water; the former is sometimes considered dangerous to the foundation by loosening the earth in the neighbour-

Machinery

Saws for cutting off piles under water.

Manufac-
tures.

hood, and the latter, although the most expensive method, is obliged to be resorted to.

The Machine employed for this purpose is required to give the saw three motions: the first by which it descends below the level of the water at the same time preserving the blade of the saw in a horizontal position; the second a horizontal motion in the direction of the length of the saw; and the third a horizontal movement in the direction of the breadth of the saw, which enables it to follow its work as it advances into the pile.

This is effected by two platforms; one of which is made movable by rollers on a framework attached to the top of the piles, where the workmen stand employed in working the saw; the other one is placed below this, and attached to it by four rods with racks and pinions, by means of which it can be raised or depressed according to the depth below the level of the water the pile is required to be cut off. The saw is fixed to a carriage which is movable on the lower platform, on rollers in the direction of the breadth of the saw; a rack is attached to the carriage which engages a pinion, working in the lower platform; by this means the carriage and saw is pressed forward against the pile.

The operation of the Machine is thus. After having fixed the two platforms horizontally, and the lower one at the required elevation, a horizontal motion is given to the saw in the direction of its length by four men upon the upper platform which causes it to cut into the timber; at the same time a man on the lower platform causes the saw to follow up its work by the rack and pinion above described, until the upper part of the pile is separated, when the Machine is moved into a new position to repeat the same operation on another pile.

A certain number of piles which cannot be cut must of course be left standing to support the Machine. These, however, need be very few, and may be drawn without risking the safety of the foundation.

The above Machine is principally used on the Continent, where caissons are employed in forming foundations under water. The caisson is a large pontoon or boat, the bottom of which is horizontal, and composed of beams well braced together. The sides are made of timber, calked so as to be perfectly water tight, and constructed in such a manner that they can be detached from the bottom when required. The caisson is placed over the spot where the erection is to be made, and built inside with masonry until it sinks, which it does on the top of piles previously driven and cut off, so that their tops preserve a perfectly horizontal plane. The sides of the caisson are then removed, leaving a thickness of masonry on the piles. In the same manner other thicknesses are added, until the masonry reaches the water's edge, when of course the building is carried on after the usual manner employed in other erections.

(537.) *Saws for cutting stone.*—These saws differ from those used in cutting wood in having no teeth upon them. Their action is therefore not that of cutting the stone, but the separation of the particles of the material they act upon by friction. Their effect is much increased by the addition of sand and water, which softens the stone and causes the particles to separate much more readily. The saw used in the common operation of sawing stone consists of a flat blade of iron fastened in a rectangular wooden frame, the saw forming the lower side of the rectangle. It is worked by a man who sits at one end, and gives a horizontal reciprocating motion by alternately pushing it from him and pulling it towards him.

When large slabs are required to be cut, the work is generally performed by two men, who sit one at each end of the stone. A board is placed so as to slope towards the fissure made by the saw, at the upper part of which a vessel of water is placed, which keeps a continual supply of water running down the board into the opening. A quantity of sand previously washed is also placed on the board at a little distance from the point at which the water is running, a portion of which the workman, by means of a stick with a hook at the end, pulls forward into the running water, which carries it down gradually into the fissure made by the saw.

The quality of the sand is varied according to the nature and hardness of the stone to be cut. For hard stone the sand is required to be very fine, but for soft stone, such as some kinds of Portland and Bath stone, the work is executed much more quickly by coarse sharp sand. The sand is required to be well cleaned, so as to be free from all extraneous matter, and sifted so that none of the particles exceed a certain size, which, as before observed, are varied according to the nature of the stone. That the sand should be perfectly clean is a matter which is required particularly to be attended to; for if a small piece of wood, or a grain so large that it will not penetrate but rolls over the stone, gets among the sand, the action of the saw is at once destroyed, and such an impediment when once got into the fissure made by the saw is very difficult to remove.

This method of cutting stone by hand is attended with a vast consumption of labour, as a good workman cannot cut through above twenty-five or thirty feet section of Portland stone in a day.

The work is besides very imperfectly executed, there being few workmen who can cut a slab which will not deviate considerably from the plane: an extra degree of labour and loss of material is produced by this means. These disadvantages of cutting stone by hand have led to the employment of Machinery for this purpose; and a very extensive mill has latterly been erected in London, which is said to perform, from the greater pressure it exerts on the saws, as much work in seventy hours by one saw as a man will execute in six weeks, and so true that scarcely any dressing is afterwards required.

The saws are stretched in a strong frame which receives a horizontal reciprocating motion from the steam engine. Any number of saws can be stretched in the frame at a time, according to the number and thickness of the slabs the stone or marble is required to be cut into. They are, of course, stretched perfectly parallel to each other, and the motion of the frame is in a truly vertical plane. The work must necessarily be performed with more truth than can possibly be given by the hand of man, as any irregularity in the texture and hardness of the stone will lead the saw out of the plane, unless governed by a greater power than a man can exert.

(538.) *Marble-mill.*—A plan and elevation of a mill for sawing and polishing slabs of marble is given in pl. xliii. fig. 1 and 2. The same letters refer to both figures. A A are the main timbers of the floor of the mill, and B B the level of the ground-floor. C D E F is a wooden frame, which is suspended by rods G G to the main beams of the floor with proper bearings: so that a free, horizontal, reciprocating motion may be given to it. The saw frame is attached to a cast iron box, which is movable upon the vertical post C F. By this means a reciprocating motion given to the frame C D E F by

Machinery.

Saw for
cutting
stone.

Mill for
sawing
marble.
Pl. xliii.
Fig. 1, 2.

Manufac-
tures.

a crank α on the main shaft is communicated to the saws.

The saws are made of wrought iron, and otherwise resemble those used by the common stonecutters. The saw frame H H H H is constructed of wood, and of a rectangular figure: it has several links in the shape of a stirrup, which traverse upon the two ends, to which the saws are fixed by pins. This will be better understood from fig. 3, which is a saw shown separately: Z Z is the section of the frame, and C C the above-mentioned links, to which the saws are attached; they are tightened by means of screws $d d$, which work in the links and press against an iron plate on the end of the frame. In this way there can be fixed any number of saws, and at any distance apart, according to the number and thickness of the slabs required to be cut. K K, L L are four upright posts constituting a frame, in which are placed the blocks of marble to be sawed into slabs, which serves at the same time to guide the frame of the saws. At each end there are a number of square, upright bars of iron, between which the saws pass; these bars serve to guide the saws in a truly vertical direction, and thereby insure an equal thickness in the slabs. The posts L L can be adjusted so as to make the frame of any required length for receiving different sized blocks. The cast iron box M, to which the saw frame is attached, is, as before observed, made to slide on the upright post C F of the vibrating frame C D E F. It is suspended by a rope, which goes over a pulley c , and is counterbalanced by the weight w . By this means the saws may be made to press upon their work with any degree of force. This sliding part is necessary to cause a rectilinear motion of the saws, because it is evident that the movable frame, from its pendulous motion, does not move in a straight line but in a curve. The pipe $e e$ serves to convey a supply of water to the saws while cutting; $f f$ is a small reservoir of water, supported by the frame K K, L L, which is kept constantly supplied from the pipe $e e$; $g g$ is an inclined board, also attached to the frame K K, L L, upon which is laid the sand used for cutting. The water from the reservoir $f f$ is constantly dripping upon the sand, and carries down a portion with it to supply the saw.

The slabs of marble, when separated, are removed to the other end of the mill to be polished, which operation is also here carried on by Machinery. The slab is placed on a carriage N N, which receives a lateral reciprocating motion from the Machinery, while the polisher has a longitudinal motion: in this way every part of the surface of the slab is acted upon equally. The carriage N N is supported upon rollers which run upon railways $h h$, fixed to the cross beams $i i$; j is a toothed wheel made to revolve by an endless screw on the main shaft, upon the spindle of which is a crank, which puts in motion by another crank l the toothed wheel n . The crank l can be adjusted to any length, but is at all times longer than the crank upon the spindle of the toothed wheel j ; by this means the wheel will not describe an entire revolution, but merely vibrate through an arc: o is a rack attached to a part of the carriage N N, which is engaged by the wheel n . It will thus be readily seen that the wheel n will give the carriage N N a lateral, reciprocating motion, which may be varied in extent, by the adjustable crank l , according to the dimensions of the slabs required to be polished. The polisher is put in motion by an upright frame O O, which vibrates with

the saw frame by the same crank upon the main shaft. The slab receives a continual supply of water from a reservoir Q Q, which is kept full from the feed pipe $e e$, while the workman adds the substance employed in polishing, which is varied in different parts of the process, and according to the nature of the marble.

(539.) *Polishing marble.*—The first substance should be the sharpest sand, so as to cut as fast as possible, which is to be continued until the surface becomes perfectly flat. After this the surface is rubbed with a finer sand, and frequently with a third. The next substance after the finest sand is emery of different degrees of fineness. This is followed by red powder called *tripoli*, which owes its cutting quality to the oxide of iron which it contains. Common iron stone, powdered and levigated, answers the purpose very well. Both of these give a tolerably good polish, which is however not considered sufficient, and the process is completed by a substance termed putty, which is an oxide of tin.

In the first process, which is merely that of reducing the inequalities of the surface, a variety in the size of the grains of sand is not a matter of any consequence; but in the subsequent processes a perfectly uniform quality of the sand is of the utmost importance, as if there are any particles larger or harder than the rest, the surface will be liable to be scratched so deeply as not to be removed by the emery. In order to get the sand of uniform quality it should be levigated and washed: the hard particles may in this way generally be separated, as they are generally of a different specific gravity from the rest. In the first process, the rubber or polish made use of is always made of iron, and, in fact, in all those where sand is employed iron is generally preferred. For the emery a plate of an alloy of lead and tin is used; and for the last process the rubbers consist of coarse linen cloths, such as hop-bagging wedged tightly into an iron plane. In all these processes a constant supply of small quantities of water is absolutely necessary.

Round articles of spar, gypsum, and marble are turned in the lathe with pointed instruments of steel: the pieces to be turned are attached to a wooden chuck by means of cement. Gypsum is very soft, and turned with great facility. Fluor spar and marble require the tool to be very hard, while the part to be turned requires a constant supply of water, which drops from a vessel above. After the articles are turned into the given shape, they are dressed with sand and emery, and afterwards polished with tripoli and putty.

Small specimens for collections of marbles are generally polished upon a lap, which runs in a lathe. These laps, however, ought to run with the axle perpendicular to the horizon, the face of the lap being truly flat and horizontal. The lap used for the first process should be of iron; the second of an alloy of lead and tin; and the third, which is for polishing, should be of iron with pitch. By means of some auxiliary Machinery, a number of pieces might be polished in this way at once, which would save much manual labour. Small pieces of marble may also be polished on the large Machine by cementing them with plaster on the surface of a large slab. By being placed on the same lever the large rubber sweeps them all at once.

(540.) We add here a short description of a marble-mill, in the neighbourhood of Kilkenny, which is remarkable for the simplicity of its construction and for the power which it exerts. One wheel, ten feet diameter, with twelve floats, gives motion by a crank at one end of its axle to a frame

Machinery.

Substance
employed
in polishing
marble.

Manufac-
tures.

containing twelve saws, which do the work of about twenty men. By a crank at the other end it moves a frame of five polishers, which do the work of about ten men. At this end Mr. Colliss, the inventor of the Machine, fitted a frame beneath the polishers with eight saws, and has found the power of the mill fully adequate to give them motion; so that the mill altogether may be fairly said to do the work of forty-two men daily. The saws are made of soft iron, and last about a week; they are constantly supplied with water and sand: the latter is taken out of the bed of the Nore, and washed till nothing remains but very fine and pure silicious particles. The marble taken from the mill is first polished with stone called *cove stone*, which is a brown sandstone, imported from Chester, which takes its name from being used in chimney coves. It is afterwards polished by a hone-stone, which is a piece of smooth nodule of the argillaceous iron ore, found in the hills between Kilkenny and Freshford. It receives its last polish in the mill with rags and putty.

Sawing
stone cylin-
ders.

In sawing stone for cylindrical pillars different Machinery is of course required. We have already given in sect. 341 a description of a method of boring stone pipes, which may be applied perfectly well to this purpose; but the Machinery commonly made use of differs considerably from it, and we therefore add the following description. When a complete cylindrical pillar is to be cut out of a block of stone, it is first necessary to fix upon the position of the axis of the cylinder, and then to lay the block in such a position that the axis may be parallel to the horizon. A cylindrical hole, from one to three inches in diameter, is bored entirely through the axis, and an iron bar, whose diameter is rather less than that of the tube, is put in it, so as to have sufficient room to slide freely as occasion may require. Each end of the bar should terminate in a screw on which a nut and frame may be fastened; the nut frame should carry thin flat pieces of wood or iron, each having a slit running along its middle, nearly from one end to the other, and a screw and handle must be adapted to each slit: by these means the framework at each end of the bars may be readily adjusted so as to form isosceles or equilateral triangles: the iron bar will form two corresponding angles of these triangles, the saw to be used two other corresponding angles; and another box of iron, or of wood, the two remaining angles to give sufficient strength to the whole frame. This construction, it is obvious, will enable the workman to place the saw at any proposed distance from the hole drilled through the middle of the block, and then, by giving an alternating motion to the saw frame, the cylinder may at length be cut from the block as required. This method was first described in the Collection of Machines approved by the Paris Academy.

If it is required to saw a conic frustrum from such a block, the two frames of wood must be fixed to those parallel ends of the block which are intended to coincide with the bases of the frustrum, circular grooves being previously cut in these frames to correspond with the circumferences of the two ends; the saw being worked in these grooves, will manifestly cut the conic surface from the block.

The best method of drilling a hole through the middle of the cylinder is thus. On a carriage running upon four low wheels, let two vertical pieces (each having a hole large enough to admit of the borer playing freely) be fixed two or three feet asunder, and so contrived

that the pieces and holes to receive the borer may be raised or lowered at pleasure; while the borer is prevented from sliding backwards and forwards by pieces upon its bar, which are larger than the holes in the vertical pieces, and which, as the borer revolves, press against them. A part of the boring bar between the two vertical pieces is square, and a grooved wheel with a square hole of a suitable size is placed upon it, so that a rotation may be given to the bar by an endless band which passes over the wheel, and another of larger diameter in the same plane, the latter wheel being turned by a winch handle in the usual way.

Machinery.

Snuff and Tobacco-mills.

(541.) *History of tobacco.*—Snuff and tobacco-mills are Machines employed in manufacturing the tobacco plant to the form in which it is used for smoking, for chewing, or for snuff. But before we enter upon a description of these processes, it will be interesting to take a rapid sketch of the history and the introduction of tobacco into this and other European Countries, in most of which, but particularly in England, it contributes very largely to the revenue. During the War, the Income Tax of this Country was considered, as it really was, a heavy and oppressive impost, while the tax on tobacco, drawn generally from the lower classes of Society for the indulgence of an artificially acquired taste, amounts to nearly one-quarter of the same sum, and it is paid without a murmur.

Discovery
of tobacco.

A branch of commerce thus bringing to the Revenue £3,000,000 sterling per annum, depending upon the consumption of an article, always repugnant to the natural taste, and at all times obnoxious to more than half the community from which it is raised, is a remarkable fact in political economy; and the general use of this herb amongst nearly all the Nations of the Earth, both civilized and savage, is not less so; and as such, a few particulars of its first introduction, its culture, and manufacture, will not, we presume, be unacceptable to the reader.

The first discovery of the properties of the tobacco plant, and its first application to the purposes of smoking, are entirely unknown, as the Europeans were not acquainted with it until the discovery of America by the Spaniards, where it had for some time been made use of by the natives.

The Americans of the Continent call it *petum*, and those of the Islands *yoli*. The Spaniards, who gave it the name of tobacco, took it from Tobaco, a Province of Yucatan, where they first found it and first learned its use: it is stated by others to have derived its name from the Island of Tobago.

The French at its first introduction among them gave it various names: as Nicotiana, or the Ambassador's herb, from John Nicot, then Ambassador of Francis XI. of Portugal, who brought home some with him to Lisbon, and presented it to the Grand Prior of the House of Lorraine, and to Queen Caroline de Medicis, whence it was also called Queen's herb, and Grand Prior's herb.

The first English settlement in America was made by Sir Walter Raleigh, who having, in the year 1585, raised a considerable subscription in London for the purpose, obtained from Queen Elizabeth a Charter for that purpose; and having sent two vessels to Virginia, they returned with reports highly favourable to the Country, bringing home with them pearls and tobacco.

Attempt at
making a
settlement
in America
by Sir Wal-
ter Raleigh.

This attempt was followed by another in the next year under Sir Richard Granville, who attempted to

Manufac-
tures.

settle a colony at the entrance of Roanoke river, in North Carolina; but these settlers were much harassed by the Indian natives; and being unable to maintain their ground, the remainder of them were taken up by Sir Francis Drake, and brought back again to England.

Mr. Lane, one of the Virginian adventurers, is said by some to have been the first person who brought tobacco to England; and Anderson, who has written very ably on the history of tobacco, seems to think that it might have taken its name at that time from Tobago. When we consider, however, the periods at which this Island was first discovered, settled, and populated, this conjecture does not seem probable.

In the same year, Sir Walter Raleigh fitted out two small vessels for America at Plymouth; and in the succeeding year, 1587, he fitted out three ships with one hundred and fifty persons of both sexes, who settled at Roanoke, where they found the second Colony had been destroyed by the natives: and these in their turn, being left three years unassisted, removed to Croatan, where they were supposed to have perished in like manner.

Captain Gosnol made a voyage in the year 1602, which was the first in sixteen years which had been attempted after Sir Walter Raleigh's failures; and he is said to be the first Englishman who ventured a direct route across the Atlantic Ocean, making discoveries upon the coasts commonly called New England; and although he appears to have trafficked with the Indians successfully, we have no account of his finding tobacco in these latitudes.

First per-
manent
settlement
made.

From the repeated favourable reports of Captain Gosnol and all others who had been in America, King James was induced to grant two Charters to distinct Companies, by the names of the London Adventurers and the Plymouth Adventurers. Ships were fitted out by these Companies, and the first permanent settlements were now made; but we do not at this period find any return in tobacco. The Company of London Adventurers obtained a confirmation of their Charter by the name of the Treasurer and Company of Adventurers and Planters of the City of London for the first Colony of Virginia, in the year 1610, being the seventh year of King James I. In 1618, the Colony of Virginia was found to increase, and considerable quantities of tobacco were cultivated, which at that time began to be much used in England.

History of
tobacco in
the reign of
King
James.

In 1620, King James, whose great dislike to tobacco seems to be amply recorded, issued a Proclamation which forbade the tobacco planters of Virginia from making above one hundred weight of tobacco per man. He also forbade any person to import into England any tobacco from beyond sea, unless authorized by a patent, upon pain of forfeiting the said tobacco.

The settlements in Virginia now began, however, to make rapid progress, one thousand three hundred persons being sent thither by the Virginia Company, together with suitable necessaries for the use of the Colony: but quarrels with the Indians brought on an unfortunate massacre of four hundred persons. This did not, however, affect the increase of the Colony; plantations were laid out, a well-regulated Country began to make its appearance, and Religion flourished. King James, however, still continued his opposition to the culture of tobacco; and made great exertions in the next year, 1622, to encourage the culture of mulberry trees and the propagation of silk-worms. The Virginia Company had by this year, 1626, raised a capital of

£200,000; but disagreeing amongst themselves, many selling out their shares, and others emigrating to Virginia with their families and servants, King Charles, who then reigned, considered it proper to take the business into his own hands, and to establish a Royal Government. This measure seems to have given a tone to the Government of Virginia; and from the encouragement given by this Monarch, by granting lands upon the easy terms of two shillings per annum quit-rent, payable to the Crown for each hundred acres, many respectable families were induced to emigrate to that Country.

Machinery

In 1633, the Colony of Maryland was established by Lord Baltimore, who carried two hundred persons to the new Settlement. It soon flourished and produced nearly as much tobacco as Virginia. The tobacco they produced is called Oroonoko, which, although not approved of generally by the English, was preferred by all the Northern nations.

Colony of
Maryland
established
by Lord
Baltimore.

About the middle of this century, tobacco seems to have grown into much greater esteem than formerly in England; considerable quantities were planted in several Counties, which thrived exceedingly well; but as this not only lessened the duty on the importation of tobacco, but likewise greatly obstructed the sale of that commodity from the Colonies of Virginia, which had cost so much expense in planting them, the loud complaints of the planters occasioned an Act of the Rump Parliament, in the year 1652, absolutely prohibiting the planting of any in England. Cromwell and his Council, in the year 1654, accordingly appointed Commissioners for strictly putting this Act into execution, but tobacco, notwithstanding, continued to be grown in considerable quantities.

Until the reign of James II. it appears that tobacco had been taxed only under the general name of poundage, but Parliament then stepped forward and granted a tax upon tobacco nominally; so that, by this law, Government drew an increase of revenue from this resource, over and above the demand of one shilling in the pound, or five per cent. poundage.

These proceedings of the year 1685 seem to be every thing that occurred which affected the commerce of tobacco materially during the reign of this Monarch. But the Revocation of the Edict of Nantes by the French King, brought on an emigration, which, under the patronage of the Crown, proved of material consequence to Virginia and the tobacco trade.

The Revocation of the Edict of Nantes occasioned a number of French families to take refuge under the protection of the Crown of England; and King William having offered them his patronage, and granted them lands in Virginia in 1690, a settlement was formed by them at the Manakin towns, formerly occupied by the aborigines of the soil, and one of the most fertile and eligible tracts of country in all America. It is situated on the South bank of James River, a few miles above the Falls, and must have proved a strong barrier against Indian encroachments upon the English settlements, as well as the means of affording considerable supplies.

In this same year, 1690, the Governor of New York, in alliance with the Irroquois Indians, made an attempt upon Quebec.

The commerce in tobacco from this time until the American War gradually increased. In the year 1772 the tobacco which was imported from Virginia and

Manufac-
tures.

Maryland into Great Britain was 54,915,282 pounds into England, and 42,883,981 pounds into Scotland; making a total importation for that year of 97,799,263 pounds; and the exportations for the same year were from England 7458 pounds, none having been exported from Scotland: the British consumption, confined to this year, must therefore have been 97,791,805 pounds.

The imports of tobacco into Great Britain in 1773 were 100,472,007 pounds; 55,928,957 pounds were imported to England, and the remainder 44,543,050 to Scotland. The exports for this year were 50,386,925 pounds from England, and 46,389,518 pounds from Scotland, making a total export of 96,776,443 pounds; so that the consumption of Great Britain for the year 1773 may be reckoned at 3,695,564 pounds of tobacco, although the exports from Scotland exceeded her imports.

The importation for the next year, 1774, was into England 56,048,957 pounds, into Scotland 41,397,252 pounds, making a total importation into Great Britain of 97,397,252 pounds. The exportation from Great Britain for this same year was from England 44,819,851 pounds, and from Scotland 33,857,064 pounds, making a total exportation from Great Britain of 78,676,915 pounds; so that the home consumption for this year may be estimated at 18,698,337 pounds of tobacco.

As this was the last year of a good understanding between Great Britain and her Colonies, it is not to be wondered at if irregularities should be found to follow this period of disquiet, until the contending claims were adjusted by an acknowledged right of jurisdiction, in which both parties discovered their true interest. The tobacco trade, however, seems to have strove hard to avoid a part in these political disagreements; for however far these contentions might have advanced, or however greatly the non-remittance of the American trade may have been inveighed against by popular pretensions, the public records show, even in 1775, when hostilities had commenced, that the importations did not diminish, until impeded by bloodshed and confusion.

In 1775, a Bill received the Royal assent, which went to restrain and limit the trade of these two Colonies (in common with the rest) to Great Britain and Ireland, and the West Indian Islands.

A Bill was in like manner passed in the same year to prohibit all trade with the American Colonies, then in actual Rebellion, during the continuation thereof.

This Act necessarily operated to interdict the whole commerce of tobacco between Great Britain and America; and after various clamours from those concerned, and a partial injury to the British revenue, it was judged expedient to repeal such of the several Acts of Parliament as prohibited the growth and produce of tobacco in Ireland, and to permit the importation of tobacco of the growth and produce of that Kingdom into Great Britain.

Such were the results of that interruption to the regular channel of commerce, which is always inseparable from the violent agitations of any momentous revolution in the system of national jurisprudence; but although War, or legal restraint, may for a while avert the accustomed course of commerce, Nature is ever struggling to reclaim her pre-eminence when the impediments of disorganization shall be removed. Of this position the American Revolution affords a very striking example; for, although the regular channel of the tobacco trade was obstructed, yet we find a portion of it surmounting this difficulty through the whole revolutionary period, by some means or other, and the balance returning to Britain among the blessings of Peace.

(542.) The two following Tables will exhibit this progress more particularly, and show in some degree the relations which subsisted between the prospect of conciliation and the prosperity of commerce.

An Account of Tobacco imported into England, exported thence, and consumed at Home during a Period of Ten Years, from 1773 to 1783, including the American War.

Years.	Pounds weight imported.	Pounds weight exported.	Pounds weight consumed.
1773	55,928,957	50,386,925	Exports exceed. Ditto.
1774	56,048,393	44,819,851	
1775	55,965,463	43,880,865	
1776	7,275,037	16,521,412	
1777	2,146,051	2,905,406	
1778	9,077,153	2,068,175	
1779	14,017,431	3,704,436	
1780	12,299,172	2,823,005	
1781	11,386,725	3,950,815	
1782	7,203,262	2,529,146	
Total	231,347,644	173,590,036	57,757,608

The years 1776 and 1777 show a greater exportation than importation by a balance of 10,005,730 pounds; consequently, it would seem as if so much tobacco must either have been cultivated in England during these two years, smuggled into that Kingdom, or exported out of old stock on hand, which might have failed of the usual annual consumption through the turbulency of the times.

The following is a similar Table exhibiting the quantity of tobacco imported into Scotland, exported thence, and consumed at home during the same period of ten years, from 1773 to 1783.

Years.	Imported.		Exported.		Consumed.
	Manufactured.	Unmanufactured.	Manufactured.	Unmanufactured.	
1773	0	44,543,050	41,783	46,347,735	Exports exceed. Ditto. Ditto. 4,618,090
1774	30	41,348,295	62,742	33,794,322	
1775	9	45,863,154	95,352	30,228,949	
1776	100	7,423,363	234,216	23,467,160	
1777	267	294,896	109,009	5,406,668	
1778	6	2,884,374	77,986	2,296,622	
1779	12	3,138,464	128,923	2,339,649	
1780	157	5,125,638	102,304	3,024,867	
1781	100	1,952,243	213,322	1,574,735	
1782	175	2,624,807	233,458	700,837	
Total	847	155,198,284	1,399,095	149,181,946	150,581,041
		847	1,399,095	1,399,095	

Effect of
the Ame-
rican War
on the to-
bacco
trade.

Manufac-
tures.

Act to en-
courage the
growth of
tobacco in
Scotland.

Here, as the exportations for 1773, 1776, and 1777 very far exceed the importations for those years, the presumption is suggested in like manner as in the case of England, that a portion must either have been home produce, smuggled, or remaining part of the old stock through an interruption of the usual consumption.

In 1782, an Act was passed to explain an Act made in the twelfth year of King Charles, (which was a confirmation of the Act passed by the Rump Parliament, entitled "An Act for prohibiting the Planting, Setting, or Sowing of Tobacco in England or Ireland,") and to permit the use and removal of tobacco, the growth of Scotland, into England for a limited time, under certain restrictions.

By this law, the recited Act was extended to Scotland: a report was to be made to the collector and comptroller of his Majesty's Customs for Scotland of all tobacco either in possession, being the actual growth of that Country, or being then actually growing; and the like duties were imposed which had theretofore been laid upon American tobacco: such tobacco was prohibited from removal into England by land, but was permitted to be conveyed thither by water under certain restrictions, the hogsheads being marked on the outside with the words Scots Tobacco.

A penalty was annexed to the crime of altering the legal marks and certificates; and tobacco removed otherwise than duly entered, marked, and certified according to the Act, together with the cattle and carriages which were used for its conveyance, became forfeited.

Duties were also to be paid upon this tobacco without any discount; the produce of these duties were to be substituted in lieu of the suspended duties upon American tobacco; nor was any drawback to be allowed on exportation.

Under this Act, the people of Scotland were encouraged in the experiments of planting tobacco; but through various causes, this project seems to have failed of success, and the succeeding Parliament thought it advisable to pass a law by which fourpence per pound was allowed to the planter for all such tobacco as, on account

of its inferior qualities or other defect, was insufficient to support the payment of the duties.

In 1783, the American War having terminated, the serious attention of the British nation became engaged to repair the damages which an injured revenue had received from an unprofitable suspension of trade.

The consequence was an immediate increase in the quantity of tobacco imported and exported, as will be seen from the following Table, which shows the actual importations from the year 1783 to 1799.

Years.	Quantity of tobacco imported.	Years.	Quantity of tobacco imported.
1783	19,579,581	1791	54,517,738
1784	43,492,302	1792	44,057,916
1785	43,255,741	1793	24,957,034
1786	45,379,795	1794	33,070,076
1787	39,600,404	1795	22,576,212
1788	48,831,232	1796	23,608,775
1789	59,154,456	1797	26,833,870
1790	57,575,923	1798	40,652,603

The difference of the amounts imported in the different years is considered by some to be owing to the effect of a fluctuating market; but if this had been the case, we should have discovered an excess of importation in some one year or other; instead of which there seems to be grounds to suspect that the depredations of French privateering had been more successful than was generally imagined; and that the tobacco trade increased in the last year in consequence of the success of our navy.

From the above period until the present time no material variation has taken place either in the laws and regulations relating to tobacco, or the quantities exported and imported. In the years 1823, 1825, 1826, some reductions were made in the duties, which has considerably increased the importation of foreign manufactured tobacco.

The amount and effect of these changes will be seen by the following Table.

(543.) *An Account of the Quantity of Tobacco imported and exported from the United Kingdom and cleared for Consumption, together with the Rates of Duty, and Net Amount of Revenue in each Year, commencing 5th January, from 1820 to 1831, both inclusive.*

Years.	Importations.				Exportations.					
	Unmanufactured.	Manufactured, or Cigars.	Snuff.	Total.	Unmanufactured.	Foreign manufactured, or Cigars.	Foreign Snuff.	British manufactured.		Total.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	Tobacco.	Snuff.	lbs.
1820	37,393,845	..	4	37,393,849	15,426,951	..	..	106,530	6,029	15,540,470
1821	23,211,451	..	12	23,211,463	17,692,758	..	24	61,465	9,289	17,763,536
1822	35,312,435	..	579	35,313,014	8,373,775	..	540	47,308	9,289	8,430,481
1823	34,999,821	26	34	34,999,881	10,626,104	..	..	56,443	10,022	10,692,569
1824	22,115,550	15,380	9	22,130,939	8,620,737	5,260	11	58,147	28,203	8,712,358
1825	40,061,185	9,569	3,697	40,074,451	3,050,588	1,448	..	64,160	8,578	3,124,774
1826	25,828,945	58,097	10,016	25,897,058	10,220,021	2,067	3,893	47,953	7,379	10,281,313
1827	23,459,898	116,366	1,200	38,577,464	13,020,294	12,696	..	66,281	6,780	13,106,051
1828	24,944,149	47,034	2,096	24,993,279	11,026,010	14,296	615	81,826	8,473	11,131,220
1829	22,399,335	166,206	3,429	22,568,970	7,369,749	25,871	1,942	71,710	8,256	7,477,528
1830	24,489,754	253,882	173	24,743,809	9,843,526	72,022	1,244	103,249	9,652	10,029,693
1831	23,107,680	218,127	1,979	33,327,786	9,358,356	79,358	703	78,443	7,411	9,524,271

Machinery
Termination of the
American War.

TABLE continued.

Manufactures.

Machinery

Years.	Consumption.				Rate of Duty, Customs and Excise.						Net Revenue.
	Unmanufactured.	Manufactured, or Cigars.	Snuff.	Total.	Unmanufactured.			Manufactured, or Cigars.	Snuff.	Customs and Excise.	
					Of Canada.	Of the dominion of Spain and Portugal.	Of other parts.				
lbs.	lbs.	lbs.	lbs.	Per lb. s. d.	Per lb. s.	Per lb. s.	Per lb. s.	Per lb. s.	£.		
1820	16,058,483	..	25	16,058,508	4 0	6	4	Prohibited.	..	3,126,646	
1821	15,828,365	..	585	15,828,950	..	..	..	..	..	3,122,067	
1822	16,289,927	.	2,519	16,292,446	..	..	..	..	..	3,261,650	
1823	17,186,343	37	726	17,187,106	..	..	..	18	..	3,425,038	
1824	16,915,426	1,400	241	16,917,067	3 9	..	..	..	..	3,378,537	
1825	18,796,030	8,619	50	18,804,699	2 9	British	Possession	in Ame	rica.	3,245,195	
1826	17,706,327	28,415	1,361	17,736,103	..	3	9	9	..	2,658,769	
1827	18,695,779	48,862	1,186	18,745,827	..	..	..	..	..	2,826,379	
1828	18,504,510	49,648	233	18,554,391	..	..	..	..	..	2,793,875	
1829	18,819,021	66,526	218	18,885,765	..	..	..	..	..	2,849,706	
1830	19,188,431	104,898	172	19,293,501	..	..	..	..	..	2,924,265	
1831	19,418,941	114,704	193	19,533,841	..	..	..	..	..	2,964,592	

Culture of Tobacco.

Culture of tobacco.

(544.) The spots generally chosen as best suited for the growth of the tobacco plant are recently cleared lands of the best possible light black soil, situated as near to a small stream of water as they can conveniently be found, due attention being also paid to the dryness of the place. The beds or patches, as they are called, differ in size, from a small salad bed to a quarter of an acre, according to the magnitude of the crop proposed. The lands are prepared for receiving the seed in March and the early part of April, as the season suits, first by burning upon them large heaps of brushwood, straw, or other rubbish, and afterwards by digging and raking them, in the same manner as ground is usually prepared for lettuce seed, which is generally sown mixed with the tobacco seed, and which answers the double purpose of feeding the labourer and of protecting the young tobacco plant from the fly, for which purpose a border of mustard is also found an effectual remedy, as the fly prefers mustard to any other young plant.

Cutting the crop.

When the crop is sufficiently ripe to proceed to cutting, which is known by the leaves changing to a yellowish-green colour with a certain mellow appearance and protrusion of the web of the leaf, the operation is assigned to the best and most judicious hands employed in the culture. They are each provided with a strong, sharp knife, with which they cut near the ground such plants as they judge to be ripe. The plants which have thick stalks or stems are sliced down the middle of the stem, in order to admit a more free and equal circulation of air through the parts during the process of curing, and to free the plant as far as possible from such partial retention of moisture as might have a tendency to ferment and damage the staple. The plants are then laid down upon the hill where they grew, with the points of the leaves all projecting the same way, as nearly as possible, so that when the sun has had sufficient effect to render them pliable, they may more easily and uniformly be gathered into turns or bundles by the labourers who follow the cutters.

Gathering the crop.

In preparing for gathering the crop of tobacco, it is

customary to erect a kind of scaffold in various places of the tobacco ground which may happen to offer a convenient situation. This is done by lodging one end of several strong poles upon any log or fence, and resting the other end of such poles upon a transverse pole supported by forks at about five feet from the ground.

In forming this part of the scaffold in the manner of joists, the poles are placed about four feet asunder from centre to centre, so that when the sticks which sustain the tobacco plants are prepared, they may fill the space advantageously, leaving but little room upon the scaffold.

The tobacco sticks, which are formed of timber, split, in the manner of laths, into pieces of four feet in length, and about one inch and a half in diameter, are laid upon the scaffolding in order to form a platform, upon which the tobacco is laid until in a sufficiently pliable state, and otherwise in a condition to be conveyed to the tobacco house, where it is suspended that the air may pass through it in the process of curing.

The barn which is appropriated to the use of receiving and curing this crop, is generally erected by the side of each respective piece of tobacco ground, or sometimes in the woods, upon some hill or particular site which may be convenient to more than one field of tobacco.

The plants are hung upon the tobacco sticks with the points downwards, the upper part resting upon the stem of the lowest leaf, or by the split made in the stem, when that happens to be divided. In this operation, particular care must be taken to allow sufficient space between each of the successive plants for the due circulation of air. About four or five inches is the general distance, but it is varied according to the bulk of the plant. From what has been said of hanging the plants, it will be perceived that the air is the principal agent in the operation of curing, and, in fact, in many cases the only agent; but when too much moisture is discovered, it is tempered by the help of smoke from small smothered fires made of oak bark kindled upon various parts of the floor where they may seem to be most needed. In this operation it is necessary that a careful hand should be always near; for the fires must not be permitted to blaze and burn furiously, which would not only endanger the house, but

Manufac-
tures.

by occasioning a sudden overheat while the leaf is in a moist condition, do great injury to the tobacco.

When the plants have remained suspended until sufficiently cured, they are taken down one by one respectively, and the leaves being stripped from the stalk of the plant, are rolled round the butt or thick end of the leaf with one of the smallest leaves as a bandage, and thus made up into little bundles to be laid in the casks.

The proper length of time during which the operation of curing should be continued is a matter upon which the success of the crop greatly depends, and can only be judged of safely by long experience and attention, and frequent handling, as tobacco often changes its quality with the change of the weather in a very short space of time. The method commonly employed of trying it is by stretching the leaf gently over the ends of the fingers and knuckles, and if it is in good condition, it will exhibit an elastic capacity, stretching like leather, and shining with a kind of moist gloss. It must be neither so dry as to break, nor so moist as to endanger the future rotting of the leaf.

When all the small bundles are made up, they are generally stowed in bulk upon pieces of timber forming a kind of platform upon the ground, having their points all laid the same way. In this condition they go through a sweat; and, therefore, care should be taken to examine them frequently that this operation of nature may be assisted by such regulations, in respect to air, heat, and cold, &c., as circumstances and experience may dictate. They must remain in this state until the fermentation shall have so far subsided as to promise a state of permanency in the juices, so that the leaf will bear a kind of elastic extension upon the fingers, similar to what has been before described, and at the same time so clear of moisture as to obviate any doubt of the risk of moulding in the passage across the Atlantic Ocean.

Where the malady of the *feu* or other disease has affected any of the plants during the growth, as to make it doubtful whether it is safe to pack them with the stem, in consequence of the liability of the latter to decay, the stem is separated from the leaf; which operation is called *stemming*, and is performed by taking the leaf in one hand, and the end of the stem in the other, in such a way as to cleave it with the grain. When the web is thus separated from the stem, it is made up into bundles in the same way as the leaf. Formerly the stems were generally thrown away, or burned with the refuse tobacco for the purpose of soap ashes, until the introduction of snuff-mills found a more economical use for them.

The tobacco is then ready to be sent to the market, and is packed in hogsheads, regulated by law to the standard of four feet six inches in length, in the manner in which it arrives in this Country. It is generally pressed down, that the size of the article may be reduced in stowage, which at the same time makes it less liable to exterior injury. This operation, however, requires some caution, as should it be bruised by this mechanical action, it is rendered liable to ferment and rot in its passage across the Atlantic Ocean, which effect occurs to such extent that a furnace is almost constantly employed at the London Docks to burn tobacco injured from this and other causes.

Snuff-mills.

(545.) Snuff-mills are employed to reduce the stems and leaves of tobacco to a powder, in order to form the article of commerce termed snuff. They are, like most other mills, constructed in various ways; the hand-mills very much resemble the common coffee-mill, but when on a large scale and the power of water, steam, &c. is

made use of, the reduction of the material is accomplished generally by two processes, first by passing the tobacco under vertical running stones, and afterwards in pestles and mortars. In the old mills, the running stones are not commonly employed, the grinding processes being performed entirely by the pestles and mortars: it is, however, necessary in this case to cut the tobacco stalks into very small pieces, which is performed by an engine consisting of stampers or pestles with knives at their lower extremities. A barrel containing lifters is made to revolve by the Machinery immediately behind the stampers, so as to engage projecting pieces upon them, by which they are elevated, until, by the revolution of the barrel, the projecting pieces are disengaged from the lifters, when the stampers and knives fall with their own weight into a box containing the tobacco.

In order that the tobacco may be equally reduced in all parts, a horizontal reciprocating motion is given to this box by a crank put in motion from the main shaft, by means of which a different portion of tobacco is presented to the action of the knife every time it falls.

Fig. 1, plate xlv. is a representation of a mill on Pl. xlv. this construction. AA is the floor of the mill, on which Fig. 1, 2, &c. are situated the pestles and mortars BB, which are made of wood secured by iron hoops *a a*. CC is the main shaft of the mill by which motion is communicated from the water wheel, steam engine, or whatever first mover may be employed; on this shaft is situated the bevelled wheel DD, which puts in rotation by a similar bevelled wheel the vertical shaft FF. The vertical shaft has a bearing in a step *b*, fixed to strong wooden framework in the ground-floor of the mill, and in plumber blocks attached to the horizontal beams *c c*. At the upper part is fixed a toothed wheel GG, which puts in rotation by the wheels HH the spindles of the pestles. KK is the frame containing the pestles and knives to reduce the tobacco previous to its being ground in the mortars. The tobacco is situated in the box *d d*, and is reduced by the knives *e e e*, &c., which are caused to fall upon it very rapidly by a barrel situated behind, shown dotted in the figure. A horizontal shaft *h* is situated in a position at right angles to the main shaft, from which it receives motion by a bevelled wheel *f*; and on the same shaft is another bevelled wheel *g g*, which engages a wheel on the axle of the barrel and thus gives a rapid rotation to it. The box which contains the tobacco, as before observed, receives a slight horizontal motion from the Machinery, in order that all parts of the tobacco may be equally acted upon: this is effected by a toothed wheel *l l*, which is caused to rotate by a pinion situated on the shaft *h*; on the axle of this wheel is a crank which gives motion to the levers *m m*, and thus also a slow motion to the box *d d*. When the tobacco stalks are in this way reduced into sufficiently small portions, they are conveyed to the upper floor and passed through mortars, where any additional degree of fineness may be given to the snuff by the screws *n n*, which adjust the position of the pestles.

In the mills where running stones are employed, it is also necessary, as in the mill above described, that the stalks should be first cut into small pieces; but as it is not required to be reduced to so fine a state, this process is generally performed by manual labour, by means of an engine very much resembling the common hay cutting Machine.

The vertical runners are similar to those already described under the article Oil-mill, each runner being

Machinery.

Manufac-
tures.

Vertical
runners
employed
in snuff-
mills.

placed at a different distance from the centre of the vertical shaft in order that they may act upon a different part of the lower plate. In snuff-mills, it is, however, necessary, in consequence of the injury which the snuff sustains if too great weight or pressure is used, that a free motion in a vertical direction be given to the frame in which the stones revolve, so that in the event of the tobacco being in a heap, the stones rise in passing over it and do not exert any pressure beyond that of their own weight. A further reduction of this pressure is necessary with some kinds of tobacco, which is attained by a counterweight attached to a rope passing over a pulley on the vertical shaft. The action of this weight is of course a deduction from that of the stones, so that by adding to or subtracting from it, the pressure exerted by the stones may be adjusted to the kind of material required to be reduced.

In the same plate, fig. 2, is represented the Machinery connected with the pestles and mortars, where, as before stated, the snuff is reduced to a further state of fineness. A A is the wooden framework in which the mortars are placed; to this frame is attached the cast iron framework B B B B of the Machinery by which the pestles and mortars are put in motion; C C C, &c. are the mortars, which are made of the shape shown in the figure. The pestles D D D, by the revolution of the vertical shaft, roll upon the inclined surface of the mortar, by which the further reduction of the tobacco is effected. The pestles and mortars are generally made of iron, when of wood they are of a different construction, consisting of a cone working within a cone. The angle of the inner cone is made rather smaller than that of the exterior, so that the surfaces are more closely in contact in the apex than in the base; by this means the snuff is gradually reduced in fineness as it descends upon the surfaces of the cones until it arrives in the apex, where it passes out at an aperture into a vessel placed to receive it. Pestles and mortars constructed in this manner form a more important part in the grinding of tobacco than those of the description represented in the plate; the latter being employed simply to give an additional degree of fineness to some kinds of tobacco, the chief reduction of the material being performed by the vertical runners, while the former perform the entire grinding process; the variations in the degrees of fineness being effected by adjusting the cones by means of screws, so as to approach nearer or further from each other.

Referring again to plate xlv., fig. 2, E E is a horizontal shaft having bearing at a a a in plumber blocks bolted to the transverse framing b b b. It has attached to it the bevelled wheels F F F, which engage similar ones upon the vertical shafts G G G, by which motion is given to the pestles. The horizontal bevelled wheels H H H are made free to move vertically on the shafts C C C, so that they can be put in and out of gear by ropes attached to the levers c c c c, &c., whereby the workmen may remove or replenish the snuff in any of the mortars without interrupting the action of the other part of the Machinery.

(546.) In fig. 3, 4 of the plate is represented an engine for cutting tobacco for the purposes of smoking, which differs from that employed in the snuff-mills; the object of the former being to divide the tobacco into as many small fragments as possible, and of the latter to divide the leaf into parallel shreds of various degrees of thickness. It consists of a cast iron framework A A, bolted firmly to the main timbers of the floor B B, in the

Engine for
cutting
tobacco.

lower part of which are bearings to support the horizontal shaft C C, which gives motion to the cutter. The tobacco leaves, after the stalks or stems are carefully removed, are placed in square wooden frames, which, by being put one above the other, form a box into which the tobacco is pressed by means of screws. One of these frames or boxes is shown at a a in the figure; it is constructed of such exterior dimensions that it exactly fills up the space between the sides b b of the frame, while the interior is equal to the width of the cutter. The tobacco is confined in the box by a cast iron plate f f, which fits between the sides of the frame, and is pressed down by screws which work in wrought iron brackets or ears g g attached to the frame. The part of the plate which extends beyond the cutter consists simply of two ears of the width of the sides a a of the box; they are pressed down by the screw h, and consequently serve as an additional security to the steady motion of the box.

Machinery.

The cutter, or knife shown at F in the figure, is bolted to a crank or carriage D D, which has a bearing at one end on the spindle E, and at the other receives a vertical reciprocating motion from a crank upon the horizontal shaft C C.

The frame or box a a containing the tobacco is placed upon a board e e, which is moved gently forward by a carriage m, traversing upon a long horizontal screw l l, seen in fig. 4. It will thus be obvious that at every revolution of the main shaft a shred of tobacco will be cut off throughout the whole section of the box by the descent of the knife. The velocity of motion given to the screw l l is varied according to the degree of fineness to which the tobacco is intended to be cut. This is effected by different toothed wheels which fit upon the screw l l, for as the motion is given to the wheel G by the lever and crank H, it will be advanced one tooth at every descent of the knife, so that if the wheel be of larger diameter, and greater number of teeth, a great number of cuts will be made during one revolution of the wheel, and, consequently, a greater degree of fineness will be given to the tobacco.

The tobacco when it has passed through the engine is exposed to a gentle heat upon a stove, and the parts which have become caked and pressed together are pulled to pieces by a workman; it is then in the state in which it is sold for smoking.

(547.) The principal part of the great variety of the snuffs of commerce is produced from various compounds of the stalks of the tobacco leaf with a substance termed *returns*, which is a portion of the leaf divided so small by the tobacco engine as to be unfit for the purposes of smoking, of which substance a considerable quantity remains from each batch operated on by the engine. For some of the finer sort of snuffs the tobacco leaf itself is employed, as the operation of stoving, which it of course has to go through if operated upon by the engine, is found to injure the flavour when employed for snuff. The quantities of the ingredients in forming different snuffs, and even for forming the same, are so varied by different manufacturers, that it is impossible to give any definite proportions, which is partly owing to the character of the snuff being in some measure produced at the mill by sifting it at different states of the process. It may, however, be given as a general rule, that in whatever way it is prepared, the darker snuffs contain a larger quantity of leaf, while those of a lighter shade are chiefly composed of the stalk.

Variety of
snuffs.

Manufac-
tures.

In preparing a batch of snuff, the ingredients are first well mixed together, and placed in heaps to ferment, a process which generally begins to take place in a short time after the mixture is made, but much depends upon the state of the weather. Soon after the fermentation commences, the tobacco heats very rapidly, and must be immediately turned by a shovel or the whole would be very quickly spoiled; this, for a time, impedes the process of fermentation, but in a few hours afterwards the action again commences, and the tobacco must again be turned. Upon the manner of performing this operation, depends in a great measure the peculiar quality of the snuff; and it is, therefore, one which calls for the greatest attention of the manufacturer, the more particularly as the state and rapidity of fermentation is so much influenced by the weather.

Lundafoot
snuff.

The celebrated Lundafoot snuff derives its particular flavour, chiefly from having the fermentation carried to a very high pitch before the batch is turned; and it is said that its first discovery was owing to the neglect of the man attending upon the batches, and who, by getting drunk, made his master's fortune.

Another story also prevails with respect to the discovery of this snuff so much esteemed by inveterate snuff-takers, which attributes it to an accidental fire, which by scorching some hogsheads of tobacco, gave them a peculiar flavour when manufactured. This story is, however, evidently without foundation, as the snuff manufactured by Lundafoot still continues to retain a peculiar flavour which cannot be imitated by other manufacturers; a circumstance which is not likely to continue if the effect simply depended upon the degree of drying.

When the ingredients have been a sufficient length of time under the process of fermentation, they are taken to the snuff-mill to be reduced to the required degree of fineness. In some cases the whole batch is ground into one sort of snuff; but different degrees of quality and fineness may be produced from the same batch by sifting in different states of the grinding process. If it is required to have several sorts, the batch, after having been for some time exposed to the action of the pestles and mortars, is passed over a sieve to separate the finer portions. This first produce will be much darker than the two remaining, and will consist chiefly of the leaf, owing to the stalks being harder and not so readily acted upon by the pestles. The residue which does not pass through the sieve is again ground, and sifted to produce a lighter coloured snuff, and so on for a third or for any varieties that may be required.

(548.) There are, also, considerable varieties in the tobacco used for smoking, but the number is by no means so great as of snuffs; they chiefly depend upon the quality of the tobacco, while snuff, although, of course, depending in a great measure upon this circumstance, is more particularly indebted for its peculiar flavour to the processes of the manufacture. The greater part of smoking tobacco is of two kinds, *shag* and *returns*. Both are made from the same cask of tobacco, the lighter leaves being chosen for the returns, and the darker ones for the common tobacco. The only difference in the manner of preparing them being, that the former is slightly sprinkled with water previous to pressing, while the latter is dipped leaf by leaf into water so as to be thoroughly moistened. The remaining kinds of smoking tobacco owe their flavour entirely to the leaf they are made from, and generally bear the name of the Country from which the tobacco is exported.

Machinery.
Different
kinds of
tobacco.

Another form of smoking tobacco, which within a few years has become very common in England, is in Cigars. The duty on those of foreign manufacture is very high, and a great many are in consequence made in this Country, although their quality is said to be much inferior to those made abroad. We have not been able to obtain any precise account of the process employed, on account of the secrecy observed by the makers; but it is probable, whatever secret there may be in it, that it consists only in the preparation of the leaf, as the particular form given to the cigar is performed by hand, simply by rolling up the leaf.

The other processes employed in the manufacture of tobacco are so simple as scarcely to need description. The tobacco called pig-tail employed for chewing is made by a wheel similar to a rope-maker's which is turned by a boy. A table, or platform, is situated level with the centre of the wheel, at which the workman stands with an instrument consisting of a flat board with a handle to it, by which he keeps adding to the rope of tobacco until it is of sufficient thickness, when it is rolled up and pressed. The black colour is given to it in various ways, but generally by a solution of tobacco in water. Tobacco in other forms, *viz.* nigger head, &c., used for chewing, is not manufactured in this Country; and the duty upon foreign manufactured tobacco of this kind is so very high as almost to amount to a prohibition, so that its use is very limited. An imitation of this tobacco is made in England, and sold under the same name, but it is much inferior to the foreign.

MANUFACTURES.

PART II.

MECHANICAL PROCESSES AND MANUFACTURES.

Manufac-
tures.
Definitions,
&c.

(549.) We have endeavoured in the preceding Part to describe such Machines and Machinery only as could be understood, independently of any particular mechanical process or Manufacture, although from the nature of the subject we could not in all cases wholly complete the illustrations without reference to the nature of the work to be performed; these cases, however, are but few, so that we may consider the preceding Part as an illustration of the principles, construction, and general action of Machinery, and the present division of the Work as descriptive of the application of those principles to Mechanical Processes and Manufactures.

The term Manufacture, in its original signification, undoubtedly means a work performed by hand; whereas at present it almost signifies a work performed *without* hands. One would smile at hearing a shoemaker's or a tailor's workshop called a Manufactory, and yet it is strictly so according to the original meaning of the word; whereas a number of mechanical processes, depending entirely for their guidance on Machinery, and that Machinery driven by steam, is without scruple denominated a Manufactory, although, perhaps, not a hand is employed in making the article, but simply in feeding the fire-place and attending to the Engines or Machines. This, however, is of no other consequence than as it renders the application of the terms Manufacture and Manufactory somewhat arbitrary, and may furnish an apology to the reader if he find a few of the following articles arranged somewhat differently from his expectation. We shall, however, in this Part, as in the preceding, endeavour to classify the articles according to the common adoption of terms, rather than, by consulting the actual signification of the words, to place them in an order wholly at variance with the common language of practical Science. Some processes are generally spoken of under the denomination of works, as iron-works, copper-works, saltpetre-works, &c.; these will fall under the general head Works. Other operations are simply designated by naming the article made, as button-making, clock-making, &c.; these will be classed under the head Mechanical Processes and Manufactures, but divided into two classes, *i. e.* of metals and fibrous materials; and, lastly, such as do not fall properly under any of the preceding heads, will be described under the term Miscellaneous Mechanical Arts. But we have once more to observe, that if, after all, the reader should not find any article in that division of the Work in which he expects to find it, we must trouble him to consult the general index, in which every article will be found arranged in alphabetical order.

Works.

Works.

(550.) Under this term we shall describe those mechanical processes, Manufactures, &c. commonly spoken of under this denomination, as gas-works, water-works, iron-

works, &c.; but it is not thought necessary here to attend strictly to the alphabetical arrangement which has hitherto been followed. It is proposed rather to consult that order which will give the most satisfactory view, and show the dependence of one process on another, without reference to any other classification.

Mechanical
Processes.

Works employed in the Manufacture of Metals.

(551.) It would be highly interesting if we were able to precede our description of the different mechanical processes connected with the Manufacture of iron and other metals, by a history of their first discovery, and the modes of working them adopted by the Ancients; but these discoveries, except in a very few cases, of those which may be called new metals, are lost in the mazes of antiquity. Gold, silver, copper, iron, and even the compound metal brass, are spoken of as known in our most ancient histories, without any reference whatever to their Manufacture; consequently it must be in vain for us at this day to offer the least conjecture on this head. All that we can do is to state the progress of the Art, and the improvements that have taken place in it within a comparatively short period of time. In our Chapter on Mining, we have endeavoured to describe the means employed in this Country for obtaining the ores from the earth, and the further processes of stamping and pounding, in cases wherein those operations are adopted, so as to render them ready for the subsequent process of smelting, and for the Manufacture of them into bars or other forms fit for the working them into such shapes and forms, and for such purposes, as the present state of the Arts requires. We shall now, therefore, consider the ore as already obtained, and reduced to the state necessary for the subsequent stages of its Manufacture.

Iron-Works.

(552.) Iron in a malleable form has undoubtedly been known from the highest antiquity, although there is great reason to believe it was extremely scarce, and considered of great value, not like gold or silver for its beauty and purity, but from its actual uses to mankind. It is repeatedly spoken of by Moses in the *Pentateuch*, and by Homer in the *Iliad*; and that it was at that time considered of great worth, is proved by Achilles proposing a ball of iron as one of the prizes to be distributed to the victors at the Games instituted in honour of Patroclus. Indeed, the extreme difficulty of extricating the metal from the ore must in these ancient times have rendered it very scarce, and of course very valuable. Its high importance in the present day in its application to the Arts is too well known to require any remarks of ours on the subject; but it is very neatly pointed out by Fourcroy, who observes: "Without iron agriculture could not have existed, nor could the plough have rendered the earth

Manufac-
tures.

ferile. The philosopher, while he studies the progress of the human understanding, and compares the fortune and state of the different nations established on various portions of the surface of the Globe, will remark, that their iron-Works seem, in some measure, to be proportioned to their intelligence, to the advancement of reason amongst them, and the degree of perfection to which the Arts have arrived. When we consider it in this point of view, as the agent by which men, in the variety of its uses, and the numerous wants it supplies, acquire enjoyments which would be unknown to them if they did not possess these products of their industry, iron must singularly contribute to extend their ideas, to multiply their knowledge, and to conduct their spirit towards that perfectibility, which Nature has given no less as the character of the human species, than as the source of all the advantages it can enjoy."

Iron is a malleable and ductile metal, of a bluish-white colour, is susceptible of a very high polish, and of the specific gravity, variously stated, from 7.600 to 7.895.

General View of the Process of making Iron.

General
process
described.

(553.) There are several particulars connected with the conversion of iron ore to a metallic state, which require to be rather minutely described; but we think that these will be better understood by readers unacquainted with the subject, if we first, without attending to minutiae, describe generally the several steps of the process. We may then return and point out those peculiarities which require further illustration.

Roasting.

The first step to be taken after the ore has been obtained, is to submit it to a considerable degree of heat in a kiln, in order to drive off the water, carbonic acid, sulphur, and other ingredients which enter largely into the composition of the ore. This is technically called roasting or calcining, and in the process a loss of weight is sustained of from 20 to 30 per cent. The kiln is fed at the top, as the roasted ore is removed from the bottom, after having sustained the requisite degree of heat; and considerable skill is exercised in this first process; for if there be too much heat the pieces of ore, or, as it is called in Wales, the *mine*, will melt and adhere together; and if too little, they will contain a portion of water or sulphur, and are obliged to be thrown aside at the kiln as *raw* or *green mine*.

Smelting.

The next step in the process is to convert the calcined ore or mine to its first metallic state. This is effected in the blast furnace, in which proper proportional quantities of ore and coke are employed, with some other substance to act as a flux, the latter depending upon the nature of the ore; particulars of which will be described as we proceed. These materials are submitted to a strong blast, produced by some one of the powerful blowing Machines already described. (Art. 383.) As this process proceeds, the metal falls in a fluid state to a part at the bottom of the furnace called the *hearth*, which is of different dimensions in different Works; in some the quantity of fluid metal produced every twelve hours amounts to from four to six tons, and at these intervals it is generally run off, forming what is called *pig iron*.

Running off
the metal.

The method of running off may be thus described: a hole is already formed at the bottom of the hearth, which is stopped with a mixture of sand and clay during the smelting process; but when ready, the hearth is *tapped* by opening this aperture, and the metal of course issues. The stream of metal is received from this aper-

ture into a long channel formed in a sort of sand, and from this principal channel, which is called the *sow*, there proceed laterally a number of smaller channels, called *pigs*, of the well-known shape of pig iron. As the fluid proceeds down the central channel, the workman interrupts its progress every now and then by a long piece of wood, in order to cause the metal to flow into the lateral channels as it proceeds, as otherwise it would not retain sufficient fluidity to flow into these, so as to form each completely; but by stopping it as above described, the pigs are all perfectly formed in the order in which the metal flows. As soon as the metal is well set, the pigs are broken off from the central channel or *sow*, and the latter is also broken to pieces by the blows of a large sledge hammer. The quantity of metal thus obtained, compared with the quantity of roasted ore employed in its production, varies of course considerably with different ores, but the product may, at a mean estimate, be stated to amount to about 40 per cent. And we have seen that in the roasting a loss of weight has been sustained of from 20 to 30 per cent.; so that from the raw mine to the first state of pig iron, a loss is sustained of about 66 per cent., or, which is the same, it requires about three tons of raw mine to form one of pig iron.

The iron in this state of pigs is distinguished into six different kinds, depending on circumstances which will be described further on: of these, the first three, *viz.* numbers 1, 2, 3, are considered as foundry metal; they contain carbon in different degrees, but all of them in a higher degree than those selected for making the bar or malleable iron. We now proceed to describe the latter process.

(554.) Here the first step is *refining* the pig iron in the *refinery* or *run out* furnace. These are much less than the blast furnace, not being calculated to hold much above a ton. The pig iron being introduced into the refinery furnace, is kept in a state of fusion for about two hours, during which it parts with a quantity of its carbon and other impurities, and comes out, as the term implies, much more pure than in its former state.

The furnace, as we have seen, is tapped every two hours, the yield each time being about a ton; and the furnace being constantly worked by a double set of men, through day and night, ought to produce about seventy tons of metal per week; perhaps it may be considered to vary from sixty to seventy tons for each double furnace, that is to say a furnace of larger dimensions than those denominated single furnaces, and furnished with two blasts instead of one only. The iron, from the refinery furnace, is run into a long flat mould, varying of course in different Works, but commonly about twenty feet long and two feet broad: this is placed near the refinery furnace, and the metal, when the furnace is tapped, passes from the furnace to the mould, through a channel formed for the purpose. The mould is set over a cistern of cold water, to facilitate the process of cooling, and to cause the metal to set quickly, after which it is easily broken down by hammers to fit it for the next process. The loss of weight sustained in the refining amounts to about 10 per cent.; but it of course varies considerably under different circumstances. Taking, however, 10 per cent. as a medium, the proportional yield at this stage, compared with the quantity of raw mine, will be about 29 or 30 per cent.

(555.) The next process is what is technically called *puddling*, at a furnace called a *puddling* furnace, which will be described in a subsequent part of this article. It will be sufficient here to state, that about three or four hundred

Mechanical
Processes.

Refining

Puddling.

Manufac-
tures.

weight of the refined metal is introduced into the furnace, which in about half an hour begins to melt, and the puddler then commences his labour. The puddler's furnace, as will be seen in another page, more resembles an oven than a furnace, having a large iron door, through the opening to which the metal is introduced and removed, and through a small opening in the bottom of the door the process of puddling is carried on; this hole being only just large enough to receive the tool, and for the man to see his work. When the metal begins to melt, the puddler introduces an iron tool, something like a hoe, and with this turns the mass about, exposing the part not melted to the hotter parts of the furnace, and removing the melted part to the cooler, till the whole becomes fluid. He then, with his iron tool, stirs it about very diligently in all directions, exposing every part to the action of the flame; and he is obliged to be constantly changing his tool, which soon becomes red hot; it is then dipped into cold water, and he proceeds with another. During this process the liquid metal heaves and boils, giving off an elastic gas, and gradually becomes thicker and more stiff; he still, however, perseveres in stirring it as long as it will yield in this form to his tool, and even after it has assumed something like a soft or solid mass, he keeps it in constant motion: having, however, by this time divided it into about five or six separate balls, each of seventy or eighty pounds weight. In this state the workman says the iron is come to a *state of nature*, and here the puddler's labour ends. The iron is now in fact approaching its malleable state, and it only remains to give it form; in the course of which, what still is wanted to render it perfectly malleable is effected.

The balls being still at their full heat in the puddler's furnace, his *under hand* or assistant removes them with a heavy and powerful pair of tongs to an adjacent hammer, weighing about four or five tons, of the kind represented in fig. 2, plate xxxv. Here the iron receives a few heavy blows: this is called *shingling*; it makes the balls more solid, and reduces them to an oblong shape better calculated for going between the rolls; it also squeezes out a portion of the liquid cinder or oxide, which is separated from the pure iron in the puddling. Generally about twenty blows are sufficient for giving the *bloom*, as it is now called, its proper shape, provided it has been well puddled.

Shingling
and rolling.

(556.) While still hot, the bloom is transferred from the shingler to the rolling-mill, of which a description is given. (Art. 514.) It is first passed through the largest hole in the rolls, then through the next size, and so on in succession. It is received on the other side of the rolls by a boy, called a *catcher*, and handed back by him with a pair of tongs over the rolls to the roller, who, having reduced the size in one pair of rolls, passes it through different grooves in the second pair. In the latter, it is reduced to a more accurate form, and to the required width and thickness. During this process, as well as in the shingling, a portion of fluid cinder and oxide are pressed out, some flying off with violence; but the greater part falls into a hollow under the rolls, where it is afterwards gathered up and laid aside. During this process we may state, as a medium case, a further reduction in weight of about 10 per cent., which makes the yield of rough bar iron to the original raw mine as about 26 to 100; there having been a loss of weight from the first of 74 per cent.

Balling.

(557.) The next and final process is what is termed (although now according to the modern mode of working

improperly) the *balling* and final rolling. This is done by first cutting the rough bars into certain lengths, with a powerful pair of shears, of the kind described in Art. (449.); and in these lengths they are piled up into stacks by women and boys, called *plers*. The pile generally consists of five or six of these pieces, each two or three feet long, according to the nature of the finished bar required, and it is important that they should be laid as evenly as possible. The stack is now introduced into the balling furnace, which resembles in size and in most other particulars the puddling furnace; and here the mass is brought to a high welding heat, which requires, however, to be attended to with great care, and calls for considerable skill in the baller. Each pile, of which there may be ten or twelve, having attained the proper degree of heat, and being prepared to follow in proper succession, is in its turn transferred from the furnace to the rollers, and after passing backward and forward from one side of the rolls to the other, through holes of less and less capacity, the bar is produced complete, in a state fit for the use of the smith.

The loss of weight in the last process is about 10 or 11 per cent., which leaves a yield of about 23 or 24 tons of finished bar iron for every 100 tons of raw mine.

(558.) The reader will not of course understand these numbers to be given as the fixed and invariable result of the product of an iron Manufactory; the final quantity of finished iron obtained is liable to great variations according to the nature of the ore, and the manner and perfection of working; they are merely intended to give to a person wholly unacquainted with the subject a general idea of the yield that is obtained at a medium, and as such they are perhaps as nearly accurate as they could well be given. Neither must it be understood that the process, as above described, is that pursued in every iron-Work: in some cases the puddling is omitted, and in others the shingling; the iron in the latter case being passed immediately from the furnace to the rolls: there are also other varieties.

The methods we have described are those most commonly followed in Wales; but it may be well to point out one or two of the other methods here alluded to. Where the puddling is omitted, the iron is exposed to the heat of a charcoal fire, in a sort of furnace very similar to the refinery furnace, and it is continued in this situation until the metal is thought to be sufficiently decarbonized. It is very frequently stirred during the operation, and when brought to a *state of nature*, as we have before used the term, is collected into masses, and removed by tongs under a large hammer, denominated, as applied to this particular use, a *stamping hammer*, where it is beaten into cakes, which are afterwards broken up, and treated in the *balling furnace* as above described. This is the old mode of working, and the iron obtained by it is by many conceived to be of very superior quality. The heat produced is considerably inferior to that afforded by coke in the *run out furnace*; and the iron is less surrounded by the fuel than in the case just mentioned. The present charcoal fire is properly a *refinery*, and not the one which is used merely as a preliminary to the process of puddling. Here the business of decarbonization is at once completed; and the resulting metal is in the same state of purity as that yielded from the rollers, after it has been puddled by the other method. *Balling* and *blooming* followed in regular succession, and plates or bars were produced exactly as before.

According to the second mode of treatment, in which

Mechanical
Processes.

Other
modes of
Manufac-
ture de-
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Manufac-
tures.

blooming is omitted, the masses obtained from the *balling furnace* are reduced under the hammer into the form of solid, cubical blocks; and when their temperature is too much lowered to be capable of any further working, they are again heated in a fire called a *chafery*, which is urged by a powerful pair of bellows, and scarcely differs from a common smith's forge, except in being larger, and the coke upon it being heaped up to the unusual height of at least two feet. In this situation they are raised to the point of welding, and afterwards hammered out into ingots of a flattened shape. Iron bars are united to them very shortly after they are brought from the *balling furnace*, to afford a greater facility of management, in the same manner as in the making of *blooms*; and these, as before, are detached, when the ingot is sufficiently formed. The iron produced in this way is not considered so good as that afforded by either of the other processes, and is employed, for the most part, in the commonest services of the Arts. Repeated rolling or hammering is the only means of imparting the fibrous texture so necessary to good bar iron; and as this treatment is less frequent in this mode of operation, the deficiency of value in the materials obtained may very probably be referable almost exclusively to this circumstance.

The above include the whole of the important variations that are practised in the manufacture of bar iron. Other shades of disagreement may be traced in different Works; but they are of a nature too trifling and unimportant to merit any particular enumeration. The Art is still in its infancy; and the light of Chemical Science, by being brought to a focus here, cannot fail to disclose many improvements on the present mode of procedure, which will greatly abridge the expense now incident to this valuable branch of national industry.

Amount of
materials
employed
compared
with the
product.

(559.) The quantity of malleable iron produced, compared with the quantity of raw mine employed, we have seen amounts to about 23 or 24 per cent. at a medium. We may now state the quantity of coal employed. First, the coal is to be converted into coke, and in this process there is a waste of weight of about 33 per cent. or a product of 66 per cent.; and the quantity of coke and of roasted mine employed in the furnace are nearly equal; but more accurately the proportions may be stated as 100 coke to 96 roasted mine, or 66 coke to 64 roasted mine, or 100 coal to 80 raw mine, or to $26\frac{2}{3}$ pig iron, that is $3\frac{1}{3}$ tons of coals are consumed in the furnace, and 3 tons of raw mine to produce 1 ton of iron. It is also estimated that one ton of coal for every ton of iron is consumed in the kiln, and in the steam engines for the blast, and about one ton of limestone as a flux to each ton of iron. The actual weight of material consumed, therefore, in the production of a ton of pig iron may at a medium be stated as follows:

Raw mine	3 tons = 2.4 tons of roasted ore.
Coal for furnace $3\frac{1}{3}$ tons =	2.5 of coke.
Do. for kiln, &c. }	1 ton.
Engines.	
Flux.	
	—

$8\frac{1}{3}$ tons of materials for 1 ton pig iron.

This is the amount of materials requisite to produce a ton of pig iron, but we have seen that a reduction of weight takes place in converting the pig iron to the finished bar in the ratio of 33 to 24. To produce therefore a ton of finished bars, these materials must be

increased in the inverse proportion, or as 24 to 33, or in the ratio of 8 to 11. Hence to produce a ton of finished bar, there will be required

Coals for kiln, steam engine, and	} 6.53 tons
blast furnace	
Raw mine	4.12
Limestone	1.37
	— 12.02

Add to this {	Coals used in refinery, .611
	Do. in the puddling, &c. 1.90
	— 2.51

Total 14.53 tons

used in the production of one ton of finished bar.

We have thus brought under the notice of the reader in one condensed point of view the general process of an iron-Work, and a statement of the medium product of such a Work, or rather the quantity of material employed to produce a given quantity of iron in the form of both malleable and pig iron. We have before stated, that these proportions and product are by no means constant, but they may be taken as a pretty fair estimate, particularly of the Welsh iron-Works. It remains for us now to describe more particularly the nature of the different furnaces, and to enter more minutely into some of the processes hitherto but slightly alluded to, for the sake of giving the reader a concise and connected view of the operation from the beginning to the end.

(560.) *Roasting*.—This, as has been seen, is the first process, and requires but little description, although it is certain one in which considerable skill must be exercised; it is either done in kilns, or in heaps in the open air, in which alternate layers of coal and iron stone are laid on each other. These are exposed to the open air, and the mass is allowed to burn till the fire is exhausted. This process is necessary in consequence of the carbonic acid and clay, and other foreign bodies which enter largely into the composition of the ore. It is an important point to get rid of these impurities as completely as possible before the mine is used in the furnace. When this is done in kilns, the roasted ore is removed from the bottom and its place supplied above. The skill here required is in supplying a sufficient degree of heat to drive these impurities off as completely as possible without carrying the heating too far. If there be too much, the pieces of mine will be partially melted and adhere together, and if too little, some of the impurities of the ore will remain, and must be thrown aside by the *filler* into the kiln head, as raw or green mine.

Different
methods of
roasting.

(561.) *Making the coke*.—Before the coal can be employed in the blast furnace, it must be converted into coke, a substance of great importance in the manufacture of iron. There is a great difference of coal in different districts even in Wales, and a very different degree of the coking process is requisite accordingly. The method of coking in Wales, is not very economical.

The general system is to place the coal in long open heaps, containing 30 or 40 tons, laying the pieces of coal as loose and open as possible, to allow of their swelling, and covering the whole with smaller pieces so as to give the external surface a tolerably level appearance. The heap is then set on fire in different places, and suffered to burn till the whole surface is completely ignited. When this is the case, the coker covers it entirely over with the dust and ashes of former fires, to exclude the air and prevent waste, and it is left to burn out, or

Manufac-
tures.

rather to cool gradually, till it is in a proper state to be uncovered and carried to the tunnel head of the furnace.

The cooling is generally, however, expedited by pouring water upon the cokes before they are uncovered. This is sometimes done to a great extent, and is found to improve the quality of the coke, by making it harder, and expelling more of the sulphur of the coal than would be got rid of without the application of water.

By the system of open fires, much of the coal must be reduced to ashes before the air is excluded. This is more particularly the case when the wind is high, as it not unfrequently is in those mountainous and exposed situations. On a stormy night, the unremitting exertions of a double set of cokers are perhaps required on the coke hearth to keep the fires tolerably covered; and in an extensive Work, probably sixty or a hundred tons of coal may be wasted in one night in spite of all their labour.

The coke hearth of an iron-Work in full operation, presents a grand and imposing spectacle in a dark night. The long rows of flame produced by the burning of many hundred tons of coal, extended over a vast space of ground, and flickering in the wind, the black, grotesque figures of the cokers brandishing their long rakes, and partially visible through the thick lurid smoke, with the roaring of the blast and the noise of Machinery, seem to realize the descriptions of the infernal regions by Virgil or Dante, rather than any thing familiar to our experience in this habitable world.

The writer of this Essay was so fortunate as to arrive on the hills about Merthyr, on a fine summer's evening just after dark, and the scene which presented itself to his view, he will always remember as one of the most extraordinary he ever witnessed.

The coals in Monmouthshire, which are very bituminous, require from five to nine days to become thoroughly coked, while those about Merthyr take only about half or less than half that time. The coal when coked, has parted with all its moisture, tar, and hydrogen gas, and a great part of its sulphur; and according to its properties, is either of a dull jet black, with the appearance of charcoal, or exhibits a bright metallic or vitreous lustre, with a porous texture. The more carbonaceous matter it contains, the better; and those beds of coal are therefore the most esteemed which present in the fracture the dull, soft appearance of carbonized vegetable matter. Small pieces of coke may be occasionally selected of such a quality that they can hardly be discriminated from charcoal, having that fibrous texture and peculiarity of lustre by which it is characterised. Coke, indeed, may be considered only as a substitute for charcoal in the smelting of iron, and was formerly unknown as applicable to this purpose. Charcoal is at present in general use in Russia and Sweden, and indeed is used at a few Works in this Country. The iron produced from it is particularly calculated for conversion into steel; but its high price and insufficient quantity would totally preclude its general use, even were it a much greater desideratum than it is. The impurities of the coke of South Wales, or, in other words, the ashes that are left after combustion, are a very important subject for the investigation of the iron-master. They are of many different kinds, some of which are much more prejudicial to the working of the furnace than others; and the strata of coal in which these prevail the most should therefore be avoided altogether, or used with caution, mixed with other qualities of coal. If the coke, after combustion, leaves a

red ash or residuum, sulphuret of iron is indicated, the sulphur of which produces a positively bad effect on the quality of the iron smelted in the furnace. If the ashes are white, they probably contain magnesia, silice, or alumine, either singly or combined; but the two latter of these earths are only detrimental as so much extraneous matter: indeed, each, singly, may be of service as a flux, according to the nature of the iron-stone with which it comes in contact; but magnesia is injurious, as it produces an opposite effect in rendering the flux less fusible by combining with it.

(562.) *Blast furnace.*—Blast furnaces, like all the other parts and processes of iron-Works, differ very considerably in different districts, as well also in the same district in different Works. Generally, however, we may state the Welsh blast furnaces, which are amongst the largest, to consist of a square mass of masonry, with a base of from thirty to fifty feet, gradually diminishing towards the upper part to about twenty or twenty-five, and about forty or forty-five feet in height, with a roof extending from one or more sides to shelter the workmen, and to keep the cast house dry. There is also a covered communication between the top of the square masonry and the high ground at the back for the purpose of supplying the materials. The cylinder at top called the tunnel-head, is furnished with doors or openings, through which the materials are introduced to the furnace: one is seen in fig. 2. This is made of fire-brick hooped together with iron, and is about eight feet in diameter. The masonry of the whole furnace is also strongly bound together with iron ties and stays. There are arches in the centre of the four sides forming recesses in the solid masonry; the one in front to enable the men to work the furnace and run out the iron, and those at the other sides for the more convenient introduction of the blast; the blast pipes are shown in the plan, fig. 3. The blast which enters at C, fig. 1, 3, produces the greatest heat, a little above this point where the iron and the cinder are melted, and where the former drops into the cavity D, called the *hearth*; this and the part immediately above, called the *boshes*, which are from fourteen to seventeen feet in diameter, are generally made of large pieces of coarse grit or pudding-stone, carefully jointed with fire-clay, so as to resist as much as possible the intense heat to which they are exposed. Recently, however, some hearths have been constructed of fire-bricks, which are much cheaper if they will but last sufficiently long.

The black parts which are shown on the walls in fig. 1, 2, are vent flues for the escape of moisture which could not escape from such a massy building without injuring the walls when the heat is applied to the interior: *d* is the dam stone over which the melted cinder flows while the metal is retained on the hearth, till it is tapped at a hole on a level with its bottom, and *T*, which forms a bridge over this passage, is called the *tymp stone*. The part between E and A is called the *cementing part*, and contains the ore and coke mixed together, which are acted upon just as they would be in a close vessel; that is, the oxygen of the ore combines with the carbon of the coke, forming carbonic acid, or rather perhaps carbonic oxide, which is generally the case at this temperature. This change will go on, in each of the masses of ore, to the very centre, where it consists of metallic iron and earthy matter only. As soon as the oxygen is separated from the iron, the combination of carbon with the metal commences, and continues till, from the reduction of the mass below, it is in its turn brought to the melting

Mechanical
Processes.

Blasting
furnace de-
scribed.
Pl. xlv.
Fig. 1, 2, 3.

Manufac-
tures.

point when the lime combines with the earthy part of the ore, and the liquid metal falls down. The vitreous cinder, thus separated, also becomes iron, and, being specifically lighter than the liquid iron, floats on its surface.

The melted iron occupies the part D, fig. 1, 2, in the furnace, and the cinder floats above it, till it runs off over the *dam stone*, as above stated; and the metal itself ultimately would run over the same, but, previously to this, it is let out at the tap hole, which is on a level with the bottom of the cavity which contains the iron.

The quality of the metal, with respect to its quantity of carbon, will depend upon the quantity and quality of the coke with which the ore has been surrounded in the cemented part. The appearance of the metal when it flows from the furnace will indicate when the coke has been used in excess. A substance floats upon the surface of the metal, which, when cold, has a shining appearance resembling plumbago, and is known to the workman by the name of *kish*. The presence of this substance shows that the metal is saturated with carbon; since it is found to consist principally of carbonaceous matter. If it is produced in any considerable quantity, it gives the iron-master a hint to increase the burden of his furnace, by increasing the proportion of ore.

The appearance of the cinder is, also, a good criterion for showing the working order of the furnace, as well as the quality of the iron. When the ore is not sufficiently cemented, unchanged oxide, in some cases, and the defect of carbon allow a considerable quantity of the oxide of iron to incorporate with the cinder, by which it assumes a greenish-yellow colour, which is not so favourable an appearance as the blue tint, or when it has the least colour.

In some instances, when the furnace is in very bad condition, the cinder becomes of so dark a green as to appear almost black: this arises from a great excess of oxide of iron which has escaped reduction in the furnace. This cinder is very fusible, from the presence of the oxide, and is considered a very unfavourable appearance. The cinder which has the least colour soon becomes solid after it flows from the furnace, from its containing less of the oxide of iron. This shows that the cementing process is carried on to a proper extent, by which the oxide has been converted into carburetted iron, in which state it can no longer combine with the earthy matter, and deserts it when the cemented masses are melted by the action of the blast. The blue tint in the cinder, which, in some instances, is almost as vivid as ultramarine, generally accompanies the ore, and owes its colour, in all probability, to an oxide of iron, containing less oxygen than the black oxide. This may throw some light upon the mystery of the black and red oxide of iron being combined with quantities of oxygen, which are as 2 to 3, indicating the existence of a third oxide, which, in all probability, is that to which the cinder owes its blue colour. This idea is strengthened by the fact, that it is never produced but when there is the least oxide of iron in the rest of the cinder. Much light may be thrown on the subject of iron smelting, by a series of well-directed experiments upon different proportions of the earths; but previously to such a course, it might be advisable to make a correct analysis of the best cinder, which is that freest from colour, and which at the same time fuses with the least heat.

(563.) We now come to the application of the blast. In fig. 3 are shown two blast pipes; there are sometimes three, and frequently but one. These holes, through which the blast passes, are called in Wales *twyeres*, and the general practice in that Country is to blow with three, or at least to have three, although frequently only two are used, and occasionally only one. The management of the *twyeres* requires considerable skill and practice, and the profitable working of a furnace depends very much upon the way in which this part of the business is conducted. The form of the orifice or *twyere* through which the blast is admitted to the furnace does not always assume the same aspect. The constant rushing in of the stream of cold air chills the part of the melting metal to which it is opposed on its entrance to the furnace, and produces a sort of artificial pipe or channel extending more or less into the interior. It is a rude perforated cone adhering by its base to the side of the interior of the furnace and stretching its apex horizontally towards the centre, and the different appearances which it exhibits indicate the manner in which the furnace is working, and are the signals to the workman who has charge of it to make the necessary changes in the proportion of the materials or the application of the blast: sometimes the *twyeres* will become so strong and project so far as to meet together in the middle of the furnace; when this is the case, the progress of the blast is of course much obstructed; at others, the *twyere* will drop off close to the side, which is as prejudicial as the other extreme. All these variations are met or prevented by a careful *keeper*, as this workman is called, who watches every indication of change, and takes his measures according to the emergency of the case. Sometimes he will stop one *twyere* entirely, and provide for the admission of the same blast to the furnace by increasing the size of the remaining blast pipes; at other times he will increase or diminish the total quantity of blast, or he will alter the proportions of the materials at the tunnel head. With all these precautions, he is unable always to keep the furnace in the most advantageous state of working, and, what is more extraordinary, he is unable to account for the changes that frequently occur.

There is certainly much to be learned in the iron trade before we can boast of any thing like a complete knowledge of its different processes. We observe many facts in this as well as in other branches of the manufacture, of which the most that we can say is, that they are connected with or caused by certain other accompanying facts, though we are ignorant *how* this connection exists; often, indeed, our knowledge does not extend so far.

(564.) *Blast engine*.—We have now to consider the method of generating the requisite blasts, and the mode of equalizing and applying it. It is produced by powerful steam engines, with one or two exceptions, where a great local facility of water-power obviates the necessity of steam. Water, however, can be used only where it can be depended upon in a constant and ample stream even through a dry summer, as it is of the first importance that the blast of a furnace should not be withheld even for a few hours. Instances have been known of the whole contents of a furnace becoming one solid mass from having been cooled by the accidental stoppage of the blast.

We have already (under Art. 383.) described several Machines for this purpose; it will, therefore, be sufficient to state here, that commonly the blast

Mechanical
Processes.
Engine ap-
plication of
the blast.

Manufac-
tures.

engines employed in these kinds of work are supplied with a large cylinder at the opposite end of the beam to the steam cylinder, and of double its diameter; *i. e.* four times its area. The blowing piston, therefore, will produce a volume of air at each stroke of the engine equal to four times the contents of the steam cylinder; but at a pressure of only one-fourth of that on the steam piston by the joint action of the vacuum and the steam, friction deducted. Thus, suppose that an engine with a steam cylinder fifty-four inches diameter, and a pressure of five pounds per inch of steam, is supplied with a blowing cylinder of 108 inches diameter, it will be capable of keeping up a blast at a pressure of $2\frac{1}{2}$ pounds per square inch; for it is calculated that the pressure in the steam cylinder of such an engine, deducting the friction, is about 10 pounds per square inch. This pressure may be reduced at pleasure, by working the engine more slowly, or with a lower pressure of steam in the boilers.

If the volume of air thus generated were to be passed immediately through small pipes to the twyeres, it would produce an intermitting, irregular blast, almost dying away at the end of every stroke of the engine, and exerting its utmost force between the pauses. This would be very injurious to the furnace, for which great regularity in the blast is necessary. To obviate this inconvenience the air is passed from the engine into a large iron reservoir, called a regulator, from its effect in equalizing the current to the twyeres. The regulator is sometimes in the shape of a sphere, as already stated in the article referred to above, entirely closed up, with the exception of the passages for the ingress and egress of the air, and produces the required effect simply by the elasticity of the large volume of condensed air which it contains: it is then called a dry regulator. Sometimes it is in the shape of a cube or cylinder, open at the bottom, and fixed in a larger vessel or cistern of water. In this case it is called a water regulator, and the column of water at the sides keeps up the requisite pressure within; but there is an inconvenience attending this construction that is likely gradually to lead to its disuse. The introduction of moisture into a furnace with the blast has a bad effect, both on the working of the furnace and the quality of the iron produced; and it is found that the condensed air in the water regulator, exposed as it is to a large and constantly agitated surface of water, has the property of taking up a very considerable quantity of moisture in solution. This is particularly the case in summer, as the higher the temperature of the air the more moisture it is capable of dissolving. This circumstance accounts in part for the fact, that furnaces never work so advantageously in summer as in cool weather; so sensitive are they in this respect, that, after working extremely well for some time with a dry North or East wind, they will frequently change all at once when the wind veers to the West or South, with moisture or rain.

(565.) It was long thought that the disadvantage experienced in the summer months was to be attributed simply to the heat of the weather, and it was therefore thought that a cool blast was most favourable to the smelting of iron; whereas lately a patent has been taken out for heating the blast artificially before it is introduced into the furnace. Here, however, care is taken that with its increased temperature no moisture is absorbed, otherwise the effect would be injurious instead of advantageous.

Air cannot support combustion until heated to 1000° of Fahrenheit's thermometer, and therefore until it acquires that temperature, by being in contact with the heated mass, it must be acting prejudicially, and consequently the nearer it can be brought to that point before it enters the furnace the better. The heat proposed to be obtained by the patentee is about 300° of Fahrenheit. The diameter of the blast pipe at the twyeres is various, according to circumstances. With a strong pressure blast and three twyeres a diameter of three or four inches may be considered sufficient. The greater the quantity of blast introduced, the greater generally will be the quantity of iron produced, but the quality will be deteriorated. If foundery or melting iron be wanted, this must be of good quality, and the blast used must not be so great as when an inferior quality is wanted to be subsequently refined and manufactured into bar iron.

(566.) *Charge of the furnace.*—The charge of the furnace as to quantity varies of course with the magnitude of it. We have in the above description had in view generally one of the larger kind, and which we may suppose to be driving fifty charges a turn, with a burden of 6 hundred weight of roasted mine; this requires therefore 50×6 hundred weight = 15 tons of roasted ore produced from about 18 tons of raw mine. The quantity of metal run from such a furnace ought, according to the proportions we have before stated, to yield about 6 tons of pig iron every twelve hours: the quantity of coke will be about the same, that is, fifty charges at 6 hundred weight each, or 15 tons, to produce which $22\frac{1}{2}$ tons of coals will be required, and as the limestone runs about a ton for every ton of iron produced, this will be about 6 tons, so that the whole charge for the twelve hours is about 36 tons, or 72 tons for the twenty-four hours; but reckoning the weight of raw iron ore and coals originally employed for the coking, roasting, &c., the whole amount of materials consumed in such a furnace in twenty-four hours is 57 tons of coals, 36 of mine, and 12 of limestone, the production being only 12 tons of pig iron. We see, therefore, how providentially it has been contrived, that the coal and iron are found together; for were they deposited in distant Countries the expense of transfer would very much diminish the value of each material. The limestone is also generally near at hand, but this is of less consequence being used in much less quantities.

(567.) It has been seen, that such a furnace as we have been describing requires to be daily fed with more than 100 tons per day of raw material, and that at the utmost it yields only about 12 tons per day of pig iron; of course there must be in all such Works an immense accumulation of cinder. If we only reckon the quantity actually supplied to the furnace this amounts to 72 tons; and the product being 12, there must still remain a very great weight of cinder; but this weight is by no means equal to the difference between 72 and 12 tons, which would be 60 tons, but it is found that the total amount, including iron, cinder, and ashes, does not exceed 40 tons; so that 20 tons' weight has been carried off in the escape of oxygen, carbon, &c. This actual dissipation is very extraordinary, but the 40 tons remaining, or rather the 28 tons remaining, after deducting the iron, from each furnace per day, together with the cinder from the refinery and other furnaces, still leads to immense accumulations in a series of years, and they are in fact such as to give a peculiar aspect to all our iron districts.

(568.) The cinders from the forge and refinery are

Mechanical
Processes.
Application
of hot air.

Charge and
burden of
the furnace

Residuum
of the fur-
nace.

Manufac-
tures.
Working
the forge
and refining
cinders.

known to contain still so much iron as to be richer than the ore employed; and some years back Messrs. Hill and Co., of the Plymouth Works, near Merthyr, obtained a patent for the use of these as a substitute for mine for the furnace. These materials are the scoria and dross produced in the different operations of the refinery and forge. It is an oxide of iron, with but little foreign matter, and therefore containing a great proportion of iron, frequently 60 or 70 per cent. It was supposed by the patentees not to have been used before for any purpose, although it was known to contain a large proportion of iron. The contrivance of Messrs. Hill and Co. consisted in mixing the cinder with argillaceous matter, so as to form a more complete imitation of the ore in its natural state. A portion of the shale or clunch, adhering to the natural ore when first raised, was to be put into the furnace with every charge of cinder. This of course made the combination less rich or more lean, as it is termed, and thereby prevented the injurious effect which had been observed in attempts made upon it without this precaution. The experiment succeeded, but the patent was invaded, and the actions brought against those who invaded it were successfully defended, a prior use of the same method having been proved. Since which, of course, every iron-master has it in his power to avail himself of the large store of these cinders, the accumulation, perhaps, of a long series of years. Many experiments were made, but the iron turned out very faulty and bad, and it is now pretty generally admitted, that although such cinder may certainly be used and rendered productive, it can only be done to a certain extent, and can be employed only with great care. The utmost, perhaps, that can be done in this way, with our present knowledge on the subject, is to work up in future all the cinder that is produced at the forges and refining, leaving the present accumulated heaps till some new discovery in the Art shall enable the masters to employ them in larger quantities: and this has been done, it is said, to a much greater extent in Staffordshire than in Wales. It is certainly much to be desired that such an experiment should succeed, and we should imagine the time will come when this material will be found much more valuable than it can now be considered; and that when Chemical Science has made further advances, a more effectual method will be discovered of separating the metal, which is known to exist in a very large proportion and combined with so few impurities. We must be content, however, to proceed gradually. When we look back to the process of manufacturing iron twenty years ago, we have every reason to be satisfied with the progress which has been made in the knowledge and improvement of the subject; and we may confidently anticipate that the next twenty years may be equally marked by advancement. It is true that many schemes projected by scientific and experienced men have failed; that many favourite speculations, which have appeared most plausible in the closet or laboratory, have been incapable of being followed up in practice on a large scale; but this want of success should by no means dishearten us: the very failures themselves lead us on to more accurate knowledge and correct results, and thus pave the way, slowly it is true, but surely also, to ultimate success and certainty.

Our present want of knowledge is remarkably displayed in the different operations of converting pig iron into malleable or wrought iron. Pig iron is commonly supposed to be a combination of the pure metal with carbon and oxygen; bar iron is the same metal freed

from these impurities. It is not ascertained in what proportions oxygen exists in the pig; but we know that the carbon is more abundant in proportion as the iron is soft and tough. Thus then we are struck with this apparent contradiction, that the purer the iron is in the state of pig, as far at least as carbon is concerned, and in that respect the more it resembles malleable iron in its Chemical properties, the more removed it becomes from it in its appearance and Mechanical properties; the white iron of the furnace being, as will be seen, the hardest and most brittle that can be produced. It is, however, so difficult to follow up Chemical analysis and to obtain results with minute accuracy, in a process requiring intense heat, that hitherto the phenomena attendant upon the refining of pig iron, and its conversion into bars, may be said rather to be guessed at than perfectly explained.

(569.) Before quitting this first stage in the manufacture of iron, it remains for us to speak more minutely than in the former general description of the nature and character of the iron as first obtained in the form of pig. It has already been stated, that the pig iron produced in the operation of smelting is of very various qualities, according to the purpose for which it is wanted, and the circumstances under which it is manufactured. It may be divided, first, into foundry iron and forge iron; the former being used in the state of pigs, for casting; the latter being only applicable to the manufacture of bar iron. The reason of this is, that, from its nature, it is too thick when melted to adapt itself to the shape of the mould, and, when cold, is too weak and brittle to be serviceable as cast iron, even if the other objection did not exist.

But the foundry iron comes first to be described. There are three qualities of it: first, second, and third.

No. 1 foundry iron differs in its Chemical composition from the other sorts, by containing more carbon. It is, indeed, combined with as much carbon as it is capable of holding; and to effect this combination in its full extent, the coke containing the fibrous appearance of charcoal, or the purest carbon, is selected. The tendency of this combination is to render the iron soft, and to make it very fluid when melted, so that it will run into the finest and most delicate mouldings. It is used for small and ornamental castings, and any thing that requires a minute and perfect adaptation to the shape of the mould. It is distinguished in its appearance by great smoothness on the face or surface of the pig; and in the fracture it exhibits a large, dark, bright, open grain, intermixed with dead spots of a lighter colour and closer texture. When broken, the pig does not ring, but sounds rather like lead, falling dull and dead upon the block over which it is broken. It is also so soft as to yield readily to the chisel. In running from the furnace, the surface of the melted metal is smooth and dull, breaking occasionally into streaks and cracks of a darker and brighter red. When it is highly carbonized, the pigs and the cinder are frequently covered with small bright black laminæ of a substance called kish. It is a pure carburet of iron, or black lead, and evinces an excess of carbon in the pig.

No. 2 foundry iron is less carbonized than No. 1; not so soft, closer grained, and more regular in the fracture, not so fluid when melted, nor so smooth on the face of the pig; it is, however, harder and stronger, and is preferred for all the less delicate parts of Machinery, where strength and durability are required.

Mechanical
Processes.

Nature and
qualities of
pig iron.

Manufac-
tures.

These two sorts are all that are recognised in some places as foundry iron. Their being combined with so large a dose of carbon and oxygen renders them unfit for manufacture into bars; but iron of the next quality, or No. 3, having less foreign admixture in its composition, is destined indifferently for the forge or the foundry. It is used extensively for castings where great strength is required, or in situations where it is to be exposed to constant wear and tear; such as tram plates, heavy shafts, and wheels, cylinders for steam engines, and many descriptions of heavy work. It is selected for these purposes from being still harder than No. 2, and possessing so great a degree of toughness as well as hardness as to make very strong and durable castings. In appearance it differs from No. 2, in the same way as that does from No. 1, being more closely grained and more regular, and darker when broken. From its appearance, it is often called dark grey iron; by which term it is, indeed, as well known as by that of No. 3.

The next quality, *bright* iron, is never called foundry iron, although used extensively for large castings. It possesses great strength and hardness, but not fluidity enough to adapt itself to intricate or minute mouldings. It derives its name from its appearance, which is of a lighter colour and brighter lustre than that which has hitherto been described.

Mottled iron is used exclusively for the purposes of the forge, as it is too thick and brittle for the foundry. It is smooth in the fracture, hardly exhibiting any grain, and appears to be compounded of two qualities imperfectly combined, being spotted or mottled with grey and white.

White iron is supposed to contain a very small portion of carbon, less than any other sort of pig iron. It is totally unfit for casting, and is sometimes so thick as hardly to run into the pig moulds, although they are purposely made very large; and so brittle, that the largest and most unwieldy pigs may be readily broken by a blow with a sledge hammer. It is too hard to yield in any degree to the chisel. The colour of the fracture is a silvery white, shining and smooth in its texture, with a foliated or crystallized structure.

Thus we have six distinct gradations of pig iron, produced under different circumstances in the blast furnace: No. 1 and No. 2 foundry, No. 3 foundry iron, No. 4 is also occasionally used as foundry, but No. 5 and No. 6 are exclusively employed for forming malleable iron.

(570.) *Refining furnace.*—We have seen that the first step after the pig iron has been obtained is refining, the mode of which has been slightly attended to. We shall now describe the furnace and process a little more at length. This furnace is shown in fig. 4, 5. A is the recess or trough made of cast metal, the bottom consisting of freestone or brick; it is surrounded on three sides with a cavity, through which water is continually passing from the cistern C: *pp* are two pipes from a blowing Machine, inserted into the conical openings, and kept cool by water from the pipe *s*, which runs off at the pipe *n*; these are to blow the fire, which occupies the recess A. The fire being made in the trough, and filled with coke, the pigs of iron are thrown into the midst of it, and coke heaped up around them, the blast being kept up, and the outsides of the trough being kept cool by water. The metal first melts, and the blast instantly acting upon it separates a quantity of its carbon, but not nearly to the extent to which it was carried in the old method already alluded to, (Art. 559.) the metal

still remaining liquid. In this state it receives the action of the blast for some hours: we have stated two hours as the usual time, but it is frequently exposed to it much longer. It is then run off at the bottom of the trough, through an opening O, as already described, into the mould or recess D E. A large quantity of the vitreous oxide of iron also runs out, which is formed by the blast and floats on the surface of the melted metal; indeed it is through the medium of this vitreous oxide that the metal below is deprived of its carbon. The blast first destroys a portion on the surface, and then oxidates the iron thus deprived of its carbon; this forms the vitreous oxide, which floats upon the carbonated mass. The oxygen, therefore, of the floating oxide is constantly in contact with the carbon of the metal below. The stratum immediately below gives its carbon to that deprived of its carbon above, and thus the change is effected to the bottom of the trough.

(571.) *Puddling furnace.*—It has been already stated that the next step is the puddling, and in fig. 6, 7 a furnace for this purpose is represented. In fig. 6, *a* is the grate, supplied with fire through an aperture in the side called the stoke-hole, and furnished with bars at the bottom for a proper supply of air, and for the escape of the ashes; *b* is the body of the furnace, where the refined metal is placed and exposed to the heat of the flames, which are drawn from the fire by the current of air over the little brickwork division between *a* and *b*, and are turned downwards again by the inclination of the roof, so as to curl and play upon the surface of the melted iron at *b*; they are then carried through the narrow part or neck of the furnace to the stack or chimney *c*. The chimney is carried up to the height of about thirty feet, and bound together at different points with iron, to keep it firmly together. There is a damper at the top of it, by which the puddler regulates the degree of draught (and consequently heat) to his furnace; for, during some parts of his operations, he wants a more intense heat than at others. The draught and heat of these furnaces are so great that the flame is carried completely through to the top of the stack, where it comes in contact with the damper, which is frequently nearly red hot. The bottom of the furnace *dd* was formerly always composed of sand, and occasionally is so still; but the most general plan is to construct it of a thick cast iron plate, which is preserved from fusion by a coat of the oxide of iron or cinder, which is formed in puddling. An artificial bottom is thus created, and found to answer better than one constructed upon sand.

Fig. 7 is an elevation of a puddling furnace, in which the whole side is of one or more plates of cast iron lined with brick, the two sides being connected by bars at the top over the brickwork of the roof: *a* is the stoke-hole, so contrived as to be stopped with a piece of coal, which is used to equalize the heat, by preventing the ingress of air to the furnace, except through the bars at the bottom; *b* is the door, raised when necessary by the lever and chain *d*; *c* is the stack, where a portion of the chain is shown by which the damper is raised or lowered. The furnace, when first lighted, requires three or four hours before it is ready to be charged, or to receive a heat of metal, as it is called; that is, the proper quantity of refined iron.

The first department at the forge is the weighing out of these charges, and delivering them at the puddling furnaces. The general weight of the charge is about 3½ hundred weight, or from that to 4 hundred weight; it

Mechanical
Processes.

Puddling
furnace.
Fig. 6, 7.

Refining
furnace.
Pl. xlv.
Fig. 4, 5.

Manufactures.

cannot be stated with precision, as the practice varies at different Works.

The puddler being supplied with his charge, whatever it may be, of metal broken into fragments or convenient sized pieces, puts it into his furnace, closes the door, and waits its being ready, which it is frequently in half an hour. At the bottom of the door is a small hole *h*, which we have already mentioned as being only large enough for the puddler to introduce his tool, and to see his work. The first business is, so to dispose of his metal that those parts which are less exposed to the action of the flame may be drawn more immediately under its influence, so that the whole quantity may be brought to the same state, and melted as nearly as possible together, as has been already described.

In such a puddling furnace as that above described, some time is lost whenever fresh metal is introduced while it is acquiring sufficient heat, and this time cannot be well stated at less than twenty minutes or half an hour, while the whole operation does not require more than two hours; so that a large proportion of the time is thus wasted. To avoid this there have been several contrivances for heating the fresh charge of metal to a certain degree before it is introduced, and while the preceding heat is in progress. One plan is, to make the flue rather wider, so as to form a sort of recess for the reception of the fresh charge, which is placed there by the puddler's man through a small door for the purpose, without any interruption to him, and when his heat is finished it is drawn forward, and is ready for him to go on with without any delay. The simplest manner, however, is to make the body of the furnace longer than according to the usual construction, and to have a second door between that where the puddler works and the stack. This affords sufficient convenience and room for the succeeding charge of metal, which at the same time is so near the workman, that when he has completed the heat and sent the balls to the shingler, it can be instantly drawn to its place, and if put in at the right time is just in the proper state for working. With these furnaces nine heats can be worked by one man in twelve hours; and if, as is sometimes the case, the furnace is provided with three sets of men instead of two, each set working eight hours out of the twenty-four, instead of twelve, ten, or even eleven heats may be finished in the twelve hours; the additional number of turns being of course attended with a proportionate increase in the weight of the produce, without a corresponding consumption of fuel; it is therefore very recommendable for its economy.

From the puddling furnace the blooms or puddlers' balls are transferred by the puddlers under hand to the shingling hammer, and thence to the puddle rolls, where the iron is converted into rough bars. These two steps require no further illustration beyond what has been given in the general description, and only a few lines more of explanation are necessary to be added relative to the balling furnace, and final operation of forming the finished bars.

Balling furnace

(572.) *Balling furnace*.—We have already said that this so much resembles the puddling furnace as to require no distinct figure to represent it, the principal difference being, that instead of the solid iron bottom, with the protecting coat of cinder, it is of loose sand, renewed from time to time as it becomes uneven or wears away. In other respects it is like the former, a reverberating furnace heated by a coal fire at the end, the flame of

which is drawn on by the current of air, and turned down in its course to the flue by the inclination of the interior of the roof. Mechanical Processes.

The further process of cutting and piling the rough bars, as also the balling and rolling, will be sufficiently understood by referring to the general description in the leading part of this Essay, and by consulting the article Shears and Rolling-mill in our preceding division.

(573.) *Remanufacture of old iron*.—Before we quit this subject entirely, it is proposed to say a few words on the subject of the remanufacturing of old iron, which is then called faggoted iron, which is generally considered to be superior in toughness and strength to new iron. The principal manufacture of this kind in the neighbourhood of the metropolis is at Messrs. Howard and Co., King and Queen Iron-Works, Rotherhithe; although we believe it is common in all large smitheries to have a pair or two of rolls, and a furnace for re-forming worn-out or fragments of iron. There is a convenience of this sort in the smithery in the Dock-yard at Woolwich, and we believe also in most other large establishments of this kind. Manufacture of faggoted iron.

In the process as we have seen it at Messrs. Howard and Co.'s the smallest piece of iron, such as old horse-shoes, horse-nails, &c., are piled together by boys and women in old or waste pieces of new, thin plate-iron doubled up in the form and size of a medium tea-caddy, and bound up in that form by waste hoop-iron. In this form they are introduced into the furnace, and when sufficiently heated are run backward and forward through the rolls into small bars, hoop-iron, &c., which is considered not only equal in quality but superior to the best new iron. We have been much indebted in the above article to H. Jones, Esq., and to an ingenious Treatise on Iron by the Society for the Diffusion of Useful Knowledge.

Steel.

(574.) It has been observed that the history of the discovery, and the first modes of working iron, are lost in the mazes of antiquity. The discovery of steel is certainly much more recent, but still we have not been able to find any account of its first introduction, nor indeed is the distinction between iron and steel, notwithstanding the present advanced state of Chemistry, very clearly understood; we know only, that steel is a particular modification of iron, and that it is a compound of carbon and iron in an intermediate state between that of malleable and pig iron; but in what respect the dose of carbon it receives makes such a marked difference in the character of the two materials is certainly not well understood. Pure iron, indeed, is considered to be wholly divested of carbon; but it is not likely that such a piece of iron was ever produced, so that all malleable iron in some measure partakes of the property of steel, and it was probably some accidental circumstance which first led to a peculiar character being observed in iron made in a particular way. This first marked the distinction, and afterwards the term steel was used to denote the different quality; for there can be no doubt that the difference between the two was known before the cause of the distinct character was so well understood as it is at present, although we have still much to learn on the subject. Steel.

Dr. Ure, in his *Chemical Dictionary*, defines steel of. Description of.

Manufac-
tures.

simply as a modification of iron, and concerning which, he observes, our knowledge is not very precise, notwithstanding the researches of many celebrated Chemists. The increase in weight which the bars of iron receive in their conversion into steel, he states, on the authority of the proprietor of the Monkland Iron-Works, to be from four to twelve ounces per hundred weight; but this proportion does not agree with other estimates: the first proportion constituting mild and the latter very hard steel. Should the process be pushed much further than this, the steel would melt, and in the act of fusion would take an additional dose of carbon sufficient to bring it to the state of No. 1 pig iron.

Peculiar
properties
of.

The peculiar property of steel, which renders it so valuable in the Arts, is, that it may be made extremely hard, or tempered to any degree between extreme hardness and the total absence of that property. These different states are produced by raising the temperature of the steel to a certain point, and then suddenly immersing it in cold water, or some other fluid. This property renders it extremely useful in the formation of various cutting tools, springs, &c. When very hard it is brittle, resists the file, yields sparks in collision with flint, and retains magnetism for a long time. Its hardness and temper are destroyed by heating to redness, and leaving it to cool gradually. It is malleable at a red heat, is less so at a white heat; and if exposed to a higher degree of temperature, it is fused, as already stated, and returns again to the state of pig iron; its point of fusibility being 130° of Wedgewood's pyrometer; but by being repeatedly heated and hammered it becomes again malleable iron, losing by this treatment its property of hardening by immersion in water.

Different
kinds of.

Steel is sometimes described as consisting of three different kinds, under the denomination of natural steel, steel of cementation, and cast steel. The natural steel, however, so called, owes its properties to the processes employed in the treatment of the ore, as the steel of cementation does to the treatment of the bar of iron; and cast steel is this latter fused and cast. Steel is also classified under the terms blistered steel, shear, or tilted, or German steel, and ingot or cast steel; the differences will be pointed out as we proceed.

Iron is converted into steel in what is called a cementing furnace, in which bars of iron are stratified with pounded charcoal, the form and construction of which will be understood by the following description given by Mr. Collier in vol. v. of the *Manchester Memoirs*.

Cementing
furnace.
Pl. xlv.
Fig. 1, 2.

(575.) *Cementing furnace for converting iron into steel.*—A furnace for this purpose is shown in plate xlv. fig. 1, 2; the first part, fig. 1, being a section through the middle A B, and fig. 2, a plan through the line D D. The same parts of the furnace are marked with the same letters in the two figures. E E are the pots or troughs into which the bars of iron are laid that are to be converted, contained in the square part within the circular building, which in its exterior form resembles a glass-house of 22 feet diameter and 32 feet high, the upper part being terminated in a dome, in the middle of which is a hole or chimney. F is the fire-place, P the bars of the grate, and R the ash-pit; G G, &c. are the flues. H H is an arch, the inside of the bottom of which corresponds with the line I I I, &c. and the top of it is made in the form of a dome having a hole or chimney in the centre K; L L L, &c. are six chimneys. M M the dome (resembling, as stated above, the usual figure

of a glass-house) covering the whole. At N there is an arched opening through which the materials are taken in or out of the furnace, and which is closely built up when the furnace is at work. At O O are holes in each trough, through which the ends of three or four of the bars are made to project quite out of the furnace. These are for the purpose of being drawn out occasionally to examine whether the iron is sufficiently converted.

Mechanical
Processes.

The troughs are made of fire-stone, or fire-tile, the bottoms of two courses, each course being about the thickness of the single course which forms the outsides of the troughs. The insides of the troughs are of one course, about double the thickness of the outside. The partitions of the flues are made of fire-brick, which are of different thicknesses as represented in the plan, and by dotted lines in the bottom of the troughs. These are for supporting the sides and bottoms of the troughs, and for directing the flame equally round them; the great object being to communicate to the whole an equal degree of heat in every part. The fuel is put in at each end of the fire-place, and the fire is made the whole length of the pots or troughs, and kept up as equally as possible during the process.

(576.) *Process of conversion.*—The furnace being prepared and bars of iron of a proper length, viz. a little less than the lengths of the troughs, and of a proper quality, Swedish iron being commonly preferred, a layer of charcoal dust is put upon the bottom of the trough, and upon that a layer of bar iron, and so on alternately till the trough is full. It is then covered over with clay to keep out the air, which, if admitted, would effectually prevent the cementation. When the fire is put into the grate, the heat passes round by means of the flues, made as shown in the figures by the sides of the troughs. The fire is continued till the cementation is complete, which generally happens in about eight or ten days. There is a hole, as has been stated, in the side, by which the workman draws out a bar occasionally to ascertain the degree to which the transmutation has proceeded. This is determined by the blisters upon the surface of the bars. If from the appearance the bars are not sufficiently changed, the hole is again carefully closed to exclude the air, and the process continued longer; but if, on the contrary, the change be complete, the fire is extinguished, and the steel is left to cool for about eight days more, when the process for forming the *blistered* steel is complete. It is thus denominated from the blisters above spoken of which are exhibited on its surface.

Process of
conversion.

For some common purposes the steel in this state is employed, but for others it is converted from blistered steel into *tilted steel*, *shear steel*, or *German steel*, and into *ingot* or *cast steel*.

(577.) *Shear or tilted steel* is formed from the bars of blistered steel. A number of these are laid together and temporarily fastened. In this state they are introduced into the fire and heated to a welding temperature, after which they are firmly united by means of the tilt hammer and drawn out; at a second heat these masses are beaten or rolled down into bars of about 1½ inch broad and ⅜ths thick. By this process, the loose parts and seams of the bars of blistered steel are closed together, and the steel is rendered susceptible of polish, of which it was before not capable. This additional hammering improves also the malleability, and renders it peculiarly applicable to the manufacturing of edge-tools, cutting instruments, shears, &c., and on this account it receives

Shear steel.

Manufactures.

its denomination of *shear* steel; having been formerly made at Newcastle, it is sometimes called *Newcastle* steel, but the better sort coming from Germany, it is frequently also called *German* steel.

Cast steel.

(578.) *Cast steel*.—This is blistered steel fused and run into ingots, a process which was first discovered in 1750, by Mr. Huntsman of Sheffield, and was for some time kept a great secret, but the Art is now pretty well known. The furnace employed for this purpose is an air furnace, and the vessel in which the fusion is made is a crucible formed of Stourbridge clay, mixed with a small quantity of powdered coke, which makes it less liable to crack in the heating or cooling, and at the same time gives it a considerable degree of stiffness in the fire when at the greatest heat. The covers of the crucibles are formed of a somewhat more fusible clay than the other part of the vessel, and are therefore sooner vitrified; by this means they become closely luted at the time the steel is at a temperature sufficiently high to be destroyed by the oxygen of the atmosphere. Coke of the hardest kind is commonly preferred for fuel in this process, as in all others where long continued and high temperatures are necessary. The crucibles are of sufficient size to contain about thirty pounds of steel, and in general each will bear charging three times. For making the best cast steel, the superior bars of blistered steel are used, broken into small pieces, but inferior cast steel is mostly made from scraps or the waste of manufactories. The vessels being charged and the fire applied a sufficient time, the steel becomes fused, and after remaining thus a proper time, it is cast into the form of ingots in cast iron moulds. These ingots are then drawn into bars under the tilt hammer, fit for the various purposes to which it is applied, as in all the finer sorts of cutlery, &c.

Various methods of working cast steel have been recommended, but frequently they have not been found practicable by those who have followed the directions given. Sir J. Franklin, in 1795, communicated a Paper on this subject to the Royal Society, *viz.* for welding steel and malleable iron together; but Mr. Collier, in his Paper in the *Manchester Memoirs* above referred to, says, from experiments he caused to be made, it appears that the author's plan can never succeed if the cast steel be of the best quality. But, perhaps, the best recorded account of the particular working properties of steel are those given in a series of Papers in the *Philosophical Magazine* by the late Mr. Mushet. He has shown that the hardness of iron increases with the carbon which it contains, till the carbon amounts to $\frac{1}{80}$ th of the iron. At that point the hardness is a maximum, the metal acquires the lustre and colour of silver, loses its granulated appearance, and assumes a crystallized form. If more than $\frac{1}{80}$ th of carbon be added, the hardness of the compound diminishes in proportion to its quantity.

The following Table by Mr. Mushet shows the proportions of carbon which combines with iron during the formation of the different carburets:

Soft cast steel.....	$\frac{1}{120}$
Common cast steel.....	$\frac{1}{100}$
The same steel but harder.....	$\frac{1}{90}$
The same, too hard for drawing.....	$\frac{1}{50}$
White cast iron.....	$\frac{1}{25}$
Mottled cast iron.....	$\frac{1}{20}$
Black cast iron.....	$\frac{1}{15}$

The following are the specific gravities of steel in different states:

Spec. grav.

Best blistered steel before hammering..	7.31
Ditto ditto after hammering..	7.73
Very hard steel.....	7.26
Melted steel wire.....	7.5
English cast steel hammered.....	7.82 to 7.91

Mechanical Processes.

(579.) *Hardening and tempering of steel*.—One of the most remarkable properties of steel, is that of its capability of being hardened by being first heated red-hot and then suddenly cooled by immersion in cold water, oil, or other fluid. The change is greater the hotter the steel is made, and the colder the fluid is into which it is plunged. The best method is to put the steel into a charcoal fire blown to a sufficient degree of heat by bellows, at least many workmen say that steel will not harden properly without a blast. When the fire is sufficiently hot, the substance to be hardened must be put in, and a gradual blast from the bellows continued till the metal has acquired a regular red heat; it is then to be rapidly quenched in cold water, at least in most common cases; but in hardening steel in thin plates, particularly when of cast steel, quenching in water would cause them to crack, and also make them too hard, and therefore in these cases recourse is had to some substance which is not so good a conductor of heat. Oil with tallow, bees-wax with resin dissolved in it, are therefore commonly employed instead of water in these cases.

Tempering steel is effected by again submitting it to the action of the fire; in doing this, as the heat increases the hardness decreases, and when it is thus reduced to that degree of hardness which the nature of the substance or instrument requires, it is again withdrawn from the fire and quenched in cold water or other fluid. The degree of hardness is judged of by the colour the metal takes in the several stages of the heating process, and artisans know the colour which gives the temper they require in their tool or instrument under operation. When elasticity is the object sought, as in springs for watches, for gun-locks, &c., the steel is quenched when it assumes a fine blue. When a fine edge is required, as in razors, the edge is brought to a fine straw colour, when the back is commonly blue. In other cases a bright red, or dark red, or dark brown indicates the proper temperature. In tempering steel for forming artificial magnets, the ends of the bars only are reduced to the blue colour. But the harder the whole bar is left, the better the magnetism will be retained, although it is the more difficult to impart the property to it, and not only is the process more difficult, but the steel in this state does not seem to possess so great a capacity for magnetism, but all that can be given to it will be retained with greater tenacity. The following Table was given by the late Mr. Stodart to Professor Brande, in which the degrees of heat of Fahrenheit's thermometer to which steel must be heated to give out the colours are stated as below; with any heat less than 430° no colour is produced.

1. Very pale straw yellow.....	430°
2. A shade of darker yellow.....	450
3. Darker straw yellow.....	470
4. Still darker straw yellow.....	490
5. A brown yellow.....	500
6. A yellow tinged slightly with purple.....	520
7. Light purple.....	530
8. Dark purple.....	550
9. Dark blue.....	570
10. Paler blue.....	590

Colours presented by steel at different temperatures.

Manufac-
tures.

11. Still paler blue610°
12. Still paler blue with a tinge of green....630

In the production of these colours, the access of oxygen is absolutely necessary in order that it may combine chemically with the metal.

Case-
hardening.

(580.) *Casehardening*.—Steel when hardened is brittle, and iron alone is not capable of receiving the hardness steel may be brought to possess. There is nevertheless a variety of articles in which it is desirable to possess all the hardness of steel, together with the toughness of iron. These requisites are united by the Art of case-hardening, which does not differ from the making of steel, except in the shorter duration of the process. Tools, utensils, or ornaments intended to be polished, are first manufactured in iron and nearly finished, after which they are put into an iron box, together with vegetable or animal coals in powder, and cemented for a certain time. This treatment converts the external part into a coating of steel, which is usually very thin, because the time allowed for the cementation is much shorter than when the whole is intended to be made into steel. Immersion of the heated pieces into water hardens the surface, which is afterwards polished by the usual methods. Moxon's *Mechanic Exercises*, p. 56, gives the following receipt: cow's horn or hoof is to be baked or thoroughly dried and pulverized. To this add an equal quantity of bay salt; mix them with stale chamber ley, or white wine vinegar; cover the iron with this mixture, and bed it in the same in loam, or enclose it in an iron box, lay it then on the hearth of the forge to dry and harden; then put it into the fire, and blow till the lump have a blood-red heat and no higher, lest the mixture be burned too much. Take the iron out and immerse it in water to harden.

Indian
steel.

(581.) *Indian steel or wootz*.—This is considered to be the finest of all steel for cutting instruments; it is made only in small quantities, and is expensive: the nature of its manufacture was unknown till very lately, and an imitation of it has been sought with some energy, without, however, arriving at a completely satisfactory result, although a near approach to it has been lately effected by Professor Faraday. The following account of the manufacture of wootz by the natives of India, was found in the manuscript Voyage of the late Dr. Voysey.

"The furnace is a temporary circular structure of clay, from four to five feet in height, and five feet in diameter; it is sunk two feet below the surface of the ground. The fuel is charcoal, and the fire is kept up by a blast from four bullock skins, placed at right angles to each other; the muzzles resting on the upper edge of the furnace, so as to force the blast downwards. The granitic clay of the furnace is highly infusible; it is found in the neighbourhood, and is formed of the decomposition of granite rock with small pieces of quartz and felspar, and is so valued for its refractory qualities, that it is exported for the manufacture of crucibles, &c. After some days, however, if a considerable heat has been maintained, the furnace becomes semi-vitrified, and requires renewal. The cost of a furnace is from two to three rupees.

"The bellows are plied incessantly day and night; during the operation, the men are relieved every four hours, each being engaged to work twelve out of the twenty-four. They are partly protected by a screen of mud placed between them and the furnace, but the heat and exertion render their task sufficiently laborious.

"The iron is converted into steel in pine-shaped crucibles made of the same clay as the furnace, and of various sizes, according to the purpose for which the steel

is to be applied, whether for the fabrication of swords, or knives, or other articles.

Mechanical
Processes.

"In making the crucibles, the granitic clay above described is ground to a fine powder with the fragments of old furnaces and crucibles, and the whole kneaded together with the chaff of rice and oil. The vessels are defended by a luting of the same; they are covered with a similar top, but a perforation is made in the latter. No charcoal is put into the crucible, but small pieces of kanch, or the glass formed in the process, are put at the bottom of them along with the ore, and serve of course as a flux. The crucibles are arranged and steadied in the furnace occasionally by the superintendent with a long and stout rod of iron.

"The materials used in the preparation of the steel are two different kinds of iron; one from Mirtpalli, the other from Kondapur, in the proportion of three parts of the former to two of the latter. The Mirtpalli iron is derived originally from the iron sand already noticed, and is sent in the state of large amorphous masses of a reddish-grey colour, and of an extremely porous texture. The internal fracture is often iridescent. The Kondapur iron is procured from an ore found amongst the iron clay, at a place about twenty miles distant. It is said to be of a dirty brown colour, and very frangible. The iron, however, is moderately compact and of a brilliant white fracture. Occasionally it contains some ingredient which spoils the steel, rendering it excessively brittle: the natives assert that the adulteration is copper, but it is more probably arsenic. The mixture being put into the crucible, the fire is excited and kept up for twenty-four hours. It is then allowed to subside, and the crucible is taken out and placed on the ground to cool. When quite cold it is opened and a cake of steel of great hardness is found weighing on an average about a pound and a half. The cake is covered with clay and annealed in the furnace for twelve or sixteen hours; it is then taken out and cooled and again annealed; and this may be repeated a third or fourth time until the metal is rendered sufficiently soft to be worked.

"The following experiments may convey some notion of the degree of heat to which these furnaces can be raised, and which may be reckoned at 130° of Wedgwood; twenty-five rupees weight of steel which had not been submitted to the last operation, with $\frac{1}{16}$ th of a silver rupee, was fused in three hours into a button of hard steel. A piece of shelly stratum from Jhirpa fused into a sort of porcelain. A piece of hornblende schist was fused into a glass, with many globules of iron and manganese floating on the surface. The granite from the bed of the Godaveri yielded a green glass. Belkonda granite was partly run into a green glass with pieces of quartz little altered floating on the mass. Sitabaldi basalt was melted into a yellowish-green, and Jhirpa wacken into a very perfect opaque black glass."

(582.) *Damascus steel*.—This is a celebrated description of steel highly preferred for swordblades. It is generally supposed to be made of slips of thin rods or wires of iron and steel, bound together with iron wire and then melted together by heat. The most skilful workmen, however, of other Countries have in vain attempted to imitate the process, so that there is reason to think that the secret of its manufacture is unknown in Europe. The colour of the Damascus blades is a dull bluish-grey, and it scarcely exceeds in hardness common steel from the forge. Its appearance is very peculiar, showing a watery or wavy surface, which on swordblades runs from the hilt to the point, exhibiting narrow lines of about the thickness of a

Damascus
steel.

Manufactures.

harpsichord wire and which never cross each other. These wavy lines arise from a slight difference in the degrees of polish occasioned by the unequal action of acid upon the steel. This appearance has been imitated by false damasking or etching, but the genuine Damascus blade is distinguished from the false one by grinding, the waving line being obliterated by this process in the false blade, but remaining the same throughout in the real one. In the real blade, indeed, the grinding at first seems to have destroyed the watering, but it immediately reappears by rubbing it with lemon juice.

Alloys of steel.

(583.) *Alloys of steel.*—Very curious and instructive experiments on the alloys of steel with several metals, with a view to improve cutting instruments and reflecting mirrors, were made a few years back in the Laboratory of the Royal Institution, of which an account is inserted in the 18th Number of the *Journal of Science*.

Alloys of steel with platinum, rhodium, gold, and nickel may be obtained when the heat is sufficiently high. This is so remarkable with platinum, that it will fuse when in contact with steel at a heat at which the steel itself is not affected.

There are some very curious circumstances attending the alloy of silver. If steel and silver be kept in fusion together for a length of time, an alloy is obtained, which appears to be very perfect while the metals are in the fluid state, but on solidifying and cooling, globules of pure silver are expressed from the mass, and appear on the surface of the button. If an alloy of this kind be forged into a bar, and then dissected by the action of dilute sulphuric acid, the silver appears not in combination with the steel, but in threads throughout the mass; so that the whole has the appearance of a bundle of fibres of silver and steel, as if they had been united by welding. The appearance of these silver fibres is very beautiful; they are sometimes one-eighth of an inch in length, and suggest the idea of giving mechanical toughness to steel, where a very perfect edge may not be required. The most interesting result is the following. When one of silver and five hundred steel were properly fused together, a very perfect button was produced, no silver appeared on its surface; when forged and dissected by an acid, no fibres were seen, although examined by a high magnifying power. The specimen forged remarkably well although very hard; it had, in every respect, the most favourable appearance. By a delicate test, every part of the bar gave

silver. This alloy is decidedly superior to the very best steel, and this excellence is unquestionably owing to combination with a minute portion of silver. It has been repeatedly made, and always with success. Various cutting tools have been made from it of the best quality. Mr. Stodart, a very eminent cutler, assisted at these experiments, which must give the public confidence in their practical results.

Equal parts, by weight, of platinum and steel form a beautiful alloy, which takes a fine polish, and does not tarnish; the colour is the finest imaginable for a mirror. The specific gravity of this beautiful compound is 9.862. The proportions of platinum that appear to improve steel for edge instruments are from 1 to 3 per cent. While an alloy of 10 platinum with 80 steel, after lying many months exposed, had not a speck on its surface, an alloy of 10 nickel with 80 platinum was in the same circumstances covered with rust.

The alloys of steel with rhodium would prove highly valuable were it not for the scarcity of the latter metal.

Messrs. Stodart and Faraday, in a new Memoir on these alloys, published in the *Philosophical Transactions* for 1822, part ii., observe that "when pure iron is substituted for steel, the alloys so formed are much less subject to oxidation: three per cent. of iridium and osmium fused with pure iron gave a button, which, when forged and polished, was exposed with many other pieces of iron, steel, and alloys, to a moist atmosphere: it was the last of all in showing any rust. The colour of this compound was distinctly blue; it had the property of becoming harder when heated to redness and quenched in a cold fluid. On observing this steel-like character, the presence of carbon was suspected; none, however, was found, although it was carefully looked for. It is not improbable that there may be other bodies besides charcoal capable of giving to iron the properties of steel; and the authors, though they cannot agree with M. Boussingault when he would replace carbon in steel by silica or its base, they think his experiments very interesting on this point, which is worthy of further examination notwithstanding the above results. The Editor of the *Journal of Science*, in commenting upon the above alloys, considers that "a bar of the best ordinary steel, selected with precaution and most carefully forged, wrought, and tempered under the immediate inspection of the master, would afford cutting instruments as perfect and excellent as those composed of wootz or of the alloys."—*Journal*, xiv. p. 378.

Mechanical Processes.

(584.) *The following Table shows the Quantities of British Wrought and Cast Iron, Unwrought Steel, Hardware, and Cutlery exported from Great Britain in each Year, from 1820 to 1831.*

Years.	Unwrought Iron.													
	Bar Iron.		Bolting Rod Iron.		Pig Iron.		Cast Iron.		Iron Wire.		Old Iron for re-manufacture.		Unwrought Steel.	
	Quantity in Tons.	Declared value.	Quantity in Tons.	Declared value.	Quantity in Tons.	Declared value.	Quantity in Tons.	Declared value.	Quantity in Tons.	Declared value.	Quantity in Tons.	Declared value.	Quantity in Tons.	Declared value.
1820	46,469	£. 449,744	7,937	£. 82,954	5,631	£. 33,648	6,647	£. 106,087	169	£. 7,019	768	£. 6,476	438	£. 19,809
1821	50,123	434,048	8,484	79,867	7,386	38,456	6,555	92,427	248	10,142	599	4,556	695	30,557
1822	44,617	356,455	10,665	93,404	8,256	39,008	6,698	97,043	357	13,115	920	6,396	784	33,044
1823	45,699	357,959	10,596	90,771	11,304	52,148	7,269	104,096	288	11,150	18	105	654	28,022
1824	38,387	334,534	7,745	73,119	5,370	30,794	9,150	133,389	355	14,117	43	268	734	31,684
1825	25,613	...	4,835	...	2,815	...	5,944	...	203	...	72	...	533	...
1826	33,253	...	7,163	...	6,563	...	5,940	...	189	...	34	...	472	...
1827	45,284	...	7,337	...	7,095	...	6,292	...	207	...	30	...	535	...
1828	51,105	...	7,449	...	7,826	...	6,205	...	310	...	108	...	917	...
1829	56,178	...	6,475	...	8,931	...	8,219	...	329	...	226	...	714	...
1830	59,885	...	8,042	...	12,036	...	8,854	...	365	...	884	...	832	...
1831	64,012	...	6,191	...	12,444	...	10,361	...	538	...	1,413	...	1,207	...

Manufactures.

TABLE continued.

Mechanical Processes.

Wrought Iron.										
Years.	Anchors and Grapnels.		Hoops.		Nails.		Other sorts except Ordnance.		Hardwares and Cutlery.	
	Tons.	Declared value.	Tons.	Declared value.	Tons.	Declared value.	Tons.	Declared value.	Tons.	Declared value.
1820	545	£. 18,269	7,552	£. 98,254	2,847	£. 94,824	6,063	£. 214,704	6,697	£. 949,085
1821	560	21,042	7,898	90,373	3,288	101,849	6,805	225,409	9,037	1,237,692
1822	579	20,821	8,947	93,248	3,353	93,570	8,104	215,058	10,466	1,334,895
1823	1,148	37,051	7,772	83,970	3,785	99,393	8,686	209,271	10,375	1,264,444
1824	1,459	43,729	7,102	81,677	3,980	110,259	8,884	237,306	12,285	1,454,296
1825	1,395	....	5,656	....	3,555	....	8,222	....	10,980	1,391,112
1826	1,679	....	7,956	....	3,538	....	9,567	....	9,627	1,169,105
1827	1,416	....	8,505	....	3,957	....	11,620	....	12,443	1,392,879
1828	1,230	....	8,807	....	4,596	....	11,703	....	12,100	1,385,617
1829	1,253	....	9,533	....	4,528	....	11,673	....	13,028	1,389,515
1830	1,246	....	8,057	....	4,818	....	12,813	....	13,369	1,410,936
1831	1,004	....	8,229	....	4,361	....	14,013	....	16,799	1,620,631

Copper.

Copper. Process of smelting.

(585.) *Copper*, as we have seen in our article *Mining*, is obtained in considerable quantities in Cornwall, and in other parts of England and Wales. In that article we have explained the processes employed in extracting the ore, and the stamping of it in order to reduce it to a state fit for smelting. It remains for us now to describe the methods had recourse to for extracting the metal from the ore and the reduction of it to malleable copper. The only ores of copper which are wrought in the large way, and from which the copper of commerce is for the most part supplied, are the sulphureous and arsenical ores of this metal. The processes the ores undergo before the metal is rendered sufficiently pure, are numerous on account of the tenacity with which both the sulphur and arsenic combine with the copper, but they are extremely simple, and may be readily explained, consisting of little more than repeated roastings and fusions till the metal has attained the necessary ductility.

First, as we have before described, the ores are broken into small pieces. They are then, in Cornwall, roasted in a furnace of the reverberatory kind, having a very long chimney to increase the heat and to carry off the sulphur and arsenic. During the roasting, which continues about twelve hours, the ore is frequently stirred in order to expose the whole of it to the flame. It is then put into a smaller furnace, of the same form, and brought to a state of fusion, being occasionally mixed with a little lime to increase the fusibility. During this process, scoriæ containing various impurities rise and float on the surface, which are raked out and run into oblong moulds where they are left to cool, when they become hard masses and are used in building. The fused metal, which sinks by its gravity, is run out through a hole in the lower part of the furnace, which during the process of fusion is stopped with a mixture of earth and clay, as described in the article *Iron Blast Furnace*. The fused copper is conveyed into vessels suspended in a well, through which a stream of water runs, by which sudden cooling the metal is reduced to a granular state, although it is still very impure, being still mixed with sulphur and arsenic. To free it more completely from these, it is repeatedly submitted to a reverberatory furnace, and each time put into the well. In each of these fusions a

slag is continually formed on the surface more thin each time, but as this slag contains in it some copper, it is preserved and mixed with the fresh ore previously to its being put into the furnace.

After these processes have been repeated a sufficient number of times, the copper is kept at a low red-heat for two days, and is then repeatedly fused and cast into moulds about fourteen inches in length. Lastly, it is put into the refining furnace with a little charcoal, in which it is again fused; it will then bear the hammer and is fit for sale. In Anglesea, the ores are wrought nearly in the same way, but there after the ore is reduced to fragments, it is put into a kiln, the flues of which terminate in a close chamber. Heat is then applied to the ore, and the sulphur which sublimes is carried through the flue and condenses in the chamber; fresh quantities of the ore are from time to time added, and the roasting in this way is carried on for several months. The sulphur is afterwards collected, fused, and run into moulds, forming what is called brimstone. See *Sulphur Works*.

The smelting the ore is conducted after the manner above described, and it is stated that about twelve hundred weight of the roasted ore yields about one-quarter of malleable metal, and each charge of the furnace of twelve hundred weight is finished in about five hours.

In Hungary, the copper ore is treated in the same way, but the purification of the metal is accomplished by means of lead; for that purpose the metal is fused in a furnace and about one-twelfth or one-fifteenth of lead is added; this forms a scoria with the impurities of the copper, which is removed as it is formed and the copper is left in its pure state, after which it is kept fused for some time. To ascertain when the whole of the impurities of the copper have been removed, the workman takes out a little of the melted metal on the end of a smooth iron rod. If the metal be pure, this falls off when it is dipped into cold water.

The purity of the metal is also known by the redness of the scoria, that of the impure copper being always dark coloured.

The thin sheets of copper used in the Arts, are prepared when the metal is in a state of fusion in the furnace. For this purpose, when the whole of the impurities have been removed, the metal is allowed to cool to near its point of congelation. A wet broom is then

Refining.

Method of forming thin sheet copper.

Manufac-
tures.

drawn along its surface, by which means a thin layer of it is made to pass into the solid state. This is removed, and immediately plunged into water, by which it acquires a fine red colour; and the process is repeated till the whole is formed into thin sheets.

Copper
obtained by
precipita-
tion.

Copper, in a state of considerable purity, is sometimes procured from the springs which contain the sulphate of this metal. With this view, pieces of iron are put into

the water, by which the copper is precipitated, owing to the superior affinity of the iron for the acid, aided, perhaps, by a galvanic action. When the whole of the iron is dissolved, the matter deposited is raked out, and is fused in a furnace, either alone or mixed with some of the poorer copper ore.

Mechanical
Processes.

The deposit obtained in this way, when fused alone, commonly yields about fifty per cent. of copper.

(586.) Table showing the Quantities of British Copper exported from the United Kingdom, together with the Quantities and Value of Copper Ore smelted, in Cornwall and Swansea, and the Quantities produced in those Places.

Years.	British Copper.										
	Exported.						Ores, &c. sold in Cornwall.				
	Coin.	Sheets, Nails, &c.	Wire.	Unwrought.	Wrought Copper of other sorts.	Total Bri- tish Copper exported.	Quantity of Ore.	Value of Ore.	Quan- tity of Metal.	Standard.	Produce.
	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Tons.	£.	Tons.	£. s. d.	Per cent.
1820	10	58,121	8	41,155	22,663	121,985	91,473	602,441	7,508	113 15 0	8 $\frac{1}{8}$
1821	155	66,676	21	34,543	24,035	125,431	98,426	605,968	8,515	103 0 0	8 $\frac{5}{8}$
1822	802	65,070	40	25,829	22,731	113,671	104,523	663,085	9,140	104 0 0	8 $\frac{3}{4}$
1823	95	56,146	98	24,082	25,387	106,516	95,750	608,033	7,927	109 18 0	8 $\frac{1}{2}$
1824	2,134	62,920	292	19,209	23,580	106,906	99,700	587,178	7,823	110 0 0	7 $\frac{7}{8}$
1825	1,807	51,437	40	10	25,002	78,624	107,454	726,353	8,226	124 4 0	7 $\frac{5}{8}$
1826	1,450	65,264	11	2,604	26,307	95,994	117,308	788,971	9,026	123 3 0	7 $\frac{5}{8}$
1827	1,150	74,943	8	26,583	40,437	143,424	126,710	745,178	10,311	106 1 0	8 $\frac{1}{8}$
1828	15	52,412	71	21,591	48,897	124,121	130,366	756,174	9,921	112 7 0	7 $\frac{5}{8}$
1829	640	59,871	13	52,987	46,643	159,521	124,502	717,334	9,656	109 14 0	7 $\frac{3}{4}$
1830	96	66,331	16	59,722	56,443	183,154	133,904	773,846	10,748	106 5 0	8
1831	..	70,477	149	67,200	32,690	170,613	144,402	806,090	12,044	100 0 0	8 $\frac{1}{2}$

Years.	Ores sold at Swansea.						Copper sold in Devon.	Copper sold in Isle of Anglesey.	Total of Copper raised in the United Kingdom.	
	Quantity of Ore.	Value of Ore.	Quantity of Metal.	Standard.						Produce.
	Tons.	£.	Tons.	£.	s.	d.				Per cent.
1820	....	....	....	.....			..	..	619	8,127
1821	3,579	31,159	344	111	8	0	9 $\frac{3}{4}$	871	558	10,288
1822	3,539	30,967	388	98	0	0	11	716	774	11,018
1823	3,378	28,971	353	103	10	0	10 $\frac{1}{2}$	694	705	9,679
1824	5,846	49,465	605	103	8	0	10 $\frac{3}{8}$	654	623	9,705
1825	7,706	68,506	729	119	0	0	9 $\frac{1}{2}$	667	736	10,358
1826	7,052	65,278	668	121	8	0	9 $\frac{1}{2}$	615	784	11,093
1827	7,802	62,798	772	104	0	0	9 $\frac{7}{8}$	562	681	12,326
1828	10,585	83,029	977	109	7	0	9 $\frac{1}{4}$	533	757	12,188
1829	16,194	99,065	1,221	110	18	0	7 $\frac{1}{2}$	454	726	12,057
1830	13,309	94,968	1,196	104	7	0	9	510	778	13,232
1831	12,999	91,509	1,240	97	6	0	9 $\frac{1}{2}$	486	915	14,685

Tin.

Reduction
of the ores
of tin.

(587.) The ores of tin are reduced in several different ways: in Cornwall, generally after being stamped, as described in our article on Mining. It is roasted in a reverberatory furnace to drive off the sulphur, part of which is, however, acidified and unites with the copper and iron also contained in the ore; after this the ore is again washed, by which it is nearly freed from all its impurities; it is

then mixed with about one-fifth of its bulk of culm, and subjected again to the furnace for about six hours, during which the oxide of tin is reduced, and the metal collects at the bottom covered with a black scoria. The metal is then drawn off into a shallow pit, in which it is freed from scoria on its surface; it is then taken out with ladles and run into moulds. The metal thus obtained is afterwards exposed to a gentle heat in a small reverberatory furnace, by which the purest part of the metal

Manufactures

first melts, and is drawn off. This forms grain tin; what is left behind is common tin, still containing a small portion of iron, copper, and arsenic.

The water employed in the second washing contains a considerable quantity of sulphate of copper, on which account it is preserved to be afterwards decomposed by iron, and the scoria separated from the tin when drawn from the furnace, retains a good deal of the metal; this, therefore, is also reserved to be again stamped and re-melted with fresh ore.

Reduction of stream tin.

The above process is followed only for the raised ore; what is called the stream tin undergoes a different process. As the ore is here in a state approaching to powder by its first washing, and as a great many of the impurities with which it is combined in the other state are already removed, the first operation is to bruise it and pass it through wire sieves; it is then thrown with alternate layers of charcoal into a blast furnace, in which it is reduced and runs out, through a channel in the bottom, into pits, the scoria being removed as it collects and thrown again into the furnace. After this the metal is put into a large iron pot, in which it is kept in a state of fusion; and while in this state, pieces of charcoal are plunged into it, which cause a fresh quantity of scoria to be formed, and separated from the metal. It is then tried or tested by removing a quantity in a ladle and pouring it into the pot, and if it appears bright like silver and of uniform consistence, it is considered pure, and is poured into moulds, being in a state fit for the market.

The following Table shows the Quantities of British Tin exported from the United Kingdom, from 1820 to 1831.

Years.	British Tin Coined.											
	Cornwall.				Devon.				Exported.			
	blks.	cwts.	qrs.	lbs.	blks.	cwts.	qrs.	lbs.	cwts.	qrs.	lbs.	
1820	16,800	50,639	2	18	..	..	..	..	25,852	1	15	
1821	18,135	54,851	3	1	..	..	..	..	29,229	1	15	
1822	18,720	56,678	3	13	61	201	2	20	35,843	2	3	
1823	22,326	67,902	1	0	80	252	1	4	26,364	1	27	
1824	28,465	87,125	2	15	279	836	2	3	36,890	0	13	
1825	25,063	77,699	2	14	389	1,180	0	14	34,237	3	19	
1826	24,555	76,674	1	1	400	1,200	2	20	43,645	0	0	
1827	30,544	95,882	1	14	602	1,869	3	7	49,474	0	21	
1828	28,983	91,387	3	19	547	1,739	3	23	41,426	2	13	
1829	25,761	83,469	2	11	543	1,827	1	22	33,215	0	8	
1830	24,306	80,979	3	26	589	2,064	0	24	30,425	1	8	
1831	24,016	79,971	1	9	462	1,651	0	12	21,762	2	0	

Lead.

Lead ore, where found.

(588.) Another useful metal found in England, is lead; it is also very common in most Countries. In England it is found in Cornwall, Devonshire, Somersetshire, Durham, Lancashire, Cumberland, Westmoreland, and partially in other Counties; in Wales, in Flintshire, Denbighshire, Merionethshire, and Montgomeryshire; and in Scotland, in Dumfries-shire, Lanarkshire, Ayrshire, and Argyleshire. The only ore of lead from which the metal

is extracted is galena, the smelting of which is very simple. This is performed either by a blast furnace, called an ore hearth, or in a reverberatory furnace. In the former method, the ore and fuel are mixed together and exposed to the action of the blast, which quickly fuses the metal and causes it to fall into the lower part of the hearth, where it is protected from the oxygen of the blast by the scoria which floats upon its surface. When the fluid is drawn off, a sufficient quantity of it is left in the furnace to float the scoria, but when the whole is drawn off, the blast is stopped, and some lime is thrown into the furnace to concrete the scoria while the heat is being discharged. In the reverberatory furnace, which is preferred in places where there is a plentiful supply of coals, the fire is made at one end, and the flame passes over the hearth and up a flue, as already described for such furnaces in general.

Mechanical Processes.

In the latter case, the ore being already stamped and freed from as much earthy matter as possible, is put into a riddle or sieve and placed in a large vessel full of water; when by a certain motion obtained, by practice, the lighter and earthy particles are separated and thrown over the edges of the riddle, while the metallic part, being of course heavier, is retained at the bottom. With this, however, there are many impurities which can be separated only in the furnace.

Here commences the smelting process. The cleansed ore is spread upon the concave hearth, so that the flame may act upon it and release the sulphur; when this has escaped, the lead combines with the oxygen, and the oxide of lead thus formed combines with and reduces the earthy matter to a liquid which floats upon the surface of the metal, and for the rest of the operation protects it from the action of the oxygen. The temperature of the furnace is now considerably raised to separate as quickly as possible the lead from the liquid scoria; after which a great portion of the scoria is tapped off, leaving only so much behind as is necessary to protect the metal from the action of the oxygen. The fire is now slackened and a quantity of slack, or refuse pit-coal, is thrown into the furnace, which serves to diminish the heat, and to concrete the melted scoria; though this last part of the process is not well done unless powdered lime be also added. The scoria being now hardened, is broken to pieces by a rake, and thrust to the opposite side of the furnace, where it is taken out through apertures formed for the purpose. The lead is now tapped, in a manner similar to that described in the manufacture of iron, and is allowed to run into a large iron pan, where it is laded into moulds to be cast into pigs. When the ores abound with sulphate of iron, it becomes necessary to add the fluete of lime as a flux.

The scoria is still found to contain some lead, independently of that in the state of oxide, and chemically combined with it; it is therefore exposed to the heat of another furnace, being a species of blast furnace, called a slag hearth, which fuses the scoria, and causes the metal to penetrate through it, and fall into a cavity, where it is protected from the agency of the blast, and whence it is taken and cast into pigs.

Manufactures.

(589.) *The following Table shows the Quantity of British Lead, Lead Ore, &c. exported from 1820 to 1831*

Mechanical Processes.

Years.	British Lead, &c. Exported.					
	Pig and Rolled Lead and Shot.	Litharge.	Red Lead.	White Lead.	Lead Ore.	Total of British Lead and Lead Ore.
	Tons. cwt. qrs. lbs.	Tons. cwt. qrs. lbs.	Tons. cwt. qrs. lbs.	Tons. cwt. qrs. lbs.	Tons. cwt. qrs. lbs.	Tons. cwt. qrs. lbs.
1820	18,300 19 1 3	394 15 1 17	229 6 3 18	602 18 3 18	251 5 0 6	19,779 5 2 6
1821	15,645 13 3 13	573 9 0 25	242 6 0 14	652 6 2 24	286 15 0 6	17,400 10 3 26
1822	13,784 8 1 20	575 19 3 12	440 19 1 19	573 17 1 6	454 16 1 9	15,830 1 1 10
1823	14,043 10 0 27	816 7 3 5	279 16 2 22	549 2 2 12	225 7 3 19	12,914 5 1 1
1824	10,832 15 0 25	585 12 3 2	338 4 0 7	884 14 0 2	349 16 0 0	12,991 2 0 8
1825	8,615 17 2 21	831 7 0 23	337 13 1 10	616 1 1 20	139 10 0 0	10,540 9 2 18
1826	10,221 17 0 19	901 2 1 4	408 3 1 11	628 14 0 23	248 15 0 0	12,408 12 0 1
1827	13,275 2 0 12	1,139 11 2 2	534 9 3 16	1,012 5 3 21	256 8 3 10	16,217 18 1 5
1828	10,001 2 2 8	1,545 4 0 15	381 14 0 2	1,132 16 1 2	195 5 0 0	13,256 1 3 27
1829	6,831 15 1 24	463 10 1 27	381 19 1 20	750 2 1 4	219 12 0 4	8,646 19 2 23
1830	7,442 7 1 7	489 18 1 26	520 7 3 16	662 2 0 12	194 5 0 0	9,309 0 3 5
1831	6,777 9 2 18	334 13 0 12	281 4 3 5	434 17 1 14	104 5 0 0	7,932 9 3 21

Silver.

Silver ores

(590.) Silver ores, properly so called, are very rare in England, but some instances of them have occurred. The silver, however, produced in this Country, is extracted principally from lead ores, which commonly contain more or less of silver, but it is only when the latter amounts to a certain per centage that it will answer the purpose of a proprietor to attempt to extract it.

We learn from some of our early Historians, that silver was formerly extracted from mines in various parts of England and Wales. In the reign of Edward I. sixteen hundred pounds weight of silver was obtained in the course of three years, from a mine in Devonshire, which had been discovered towards the beginning of this reign; and is called a silver mine by the old writers, but it appears to have been only a mine of lead that contained silver. The lead mines in Cardiganshire have also at different periods afforded great quantities of this metal. Sir Hugh Middleton is said to have cleared from them two thousand pounds per month, and to have been enabled thereby to undertake the great work of bringing the New River from Ware to London. The same mines yielded, in the time of Charles I., eighty ounces of silver in every ton of lead, and part of the King's army was paid with this silver, which was minted at Shrewsbury. Sir J. Pettre's *Essay on Metal Works*.

A mint for the coinage of Welsh silver had been previously established at Aberystwith: the indenture was granted to Thomas Bushel, for the coinage of half-crowns, shillings, sixpences, twopences, and pennies, and the moneys were to be stamped with the ostrich feather on both sides. In 1604, nearly three thousand ounces of this Welsh bullion were minted at one time at the Tower. Webster, in his *History of Metals*, published in 1671, makes mention, from his own knowledge, of two places in Craven, in the West Riding of Yorkshire, where formerly good argentiferous lead ore had been procured. One of the places was Bronghite Moor, in the parish of Slaidburn; the ore held about the value of sixty-seven pounds of silver in the ton: the other was at Skelhornfield, in the Parish of Gisburn; it had formerly belonged to a person of the name of Pudsey, who is supposed to have coined it, as there were many shillings in that County which the common people

called Pudsey shillings. There are several smelting houses at Holywell, in Flintshire, where silver is extracted from lead; and according to Mr. Pennant, at one of the largest of these houses, in the year 1754, more than twelve thousand ounces of silver were produced, but in the subsequent years, the quantity appears to have been considerably diminished. The silver extracted from lead is sold principally to the manufacturers at Sheffield and Birmingham.

In later times, also, considerable quantities of silver have been obtained from British mines, of which the lead mines of Beralston, Devonshire, furnishes the richest supply. This mine is 110 fathoms deep, and is worked under the Tamar, and the vein which was being worked when the author visited this mine, was stated to yield about seventy ounces of silver to a ton of lead; but it has since, we believe, much declined, and the process of extraction has been discontinued. According to Mr. Mawe, it appears that at the copper mine called Huel Jewel, about four miles South-East of Callington, native silver and lead ore and certain other silver ores were found which promised well at first, but soon failed. In a lead mine at Truro, the produce of silver was one hundred ounces of silver to a ton of lead. Little silver is at this time, however, obtained from the lead works of England, and we shall not therefore detain the reader with more than a simple description of the process of extracting it. We may just add, that according to the present comparative price of lead and silver, it will not answer the purpose of a proprietor to undertake the process unless the amount of silver exceeds twenty ounces to the ton of lead.

(591.) *Process of extracting silver from lead.*—This is effected by oxidating the latter metal in a reverberatory furnace, of a particular construction for the admission of air on the surface of the lead in a state of fusion. With this object, a shallow vessel or cupel is employed, filled with prepared fern ashes, well rammed down, out of which a concavity is cut out for the reception of the lead, with an opening on one side for the mouth of the bellows, through which the air is forcibly driven during the process. The French smelters cover the surface of the ashes with hay, and arrange the pieces of lead symmetrically upon it. When the fire is lighted and the lead is in a state of fusion from the reverberation of the flame,

Extracting silver from lead.

Manufac-
tures.

the blast from the bellows is made to play forcibly on the furnace, and in a short time a crust of yellow oxide of lead, or litharge, is formed, and driven to the side of the cupel opposite to the mouth of the bellows, where a shallow side or aperture is made for it to pass over; another crust of litharge is formed and driven off, and this is repeated in succession till nearly all the lead has been converted into litharge and removed. The operation continues about forty hours, when the complete separation of the lead is indicated by a brilliant lustre on the convex surface of the melted mass in the cupel, which is occasioned by the removal of the last crust of litharge that covers the silver. The French introduce water through a tube into the cupel, to cool the silver rapidly, and to prevent its spirting out, which it does when the refrigeration is gradual, owing, probably, to its tendency to crystallize. In England, the silver is left to cool in the cupel, and some inconvenience is caused by the spirting, which might be avoided by the former mode.

The silver thus extracted is not sufficiently pure; it is again refined in a reverberatory furnace; being placed in a cupel lined with bone ashes, and exposed to greater heat, the lead which has escaped oxidation by the first process is converted into litharge, and absorbed by the ashes of the cupel. The last portions of litharge in the first process are again refined for silver, of which it contains a part which was driven off with it. The litharge is converted into lead again by heating it with charcoal; part is sometimes sold for pigment, or converted into red lead. The loss of lead by this process differs considerably, according to its quality.

Zinc.

Reduction
of zinc ores.

(592.) The ores of zinc used in Metallurgy are calamine and blend, and from these the metal is procured by a very simple process, although differing in some respect from those already described. It may be observed, however, that the methods adopted in different Countries are various, but the following is perhaps the most simple. The ore after being dressed, and the pieces of lead frequently mixed with it removed, is roasted in order to expel the sulphur, acids, and other foreign matter. The product is then washed, by which the lighter matter is separated, and the heavy part which remains is mixed with one-eighth of its weight of charcoal. The mixture is next reduced to powder in a mill, in which state it is put into pots to be smelted. The pots in which the smelting is performed, resemble oil jars in shape. Through the bottom of each there passes a tube, the upper end of which terminates by an open mouth near the top of the pot, the lower end goes through the floor of the furnace into water. The pots are filled to the upper end of the tube with the mixture of ore and charcoal, and an intense heat is applied to them by means of a furnace. As the ore is reduced, the zinc is volatilized, and escapes through the tube into the water, where it is condensed in the form of globules. These are afterwards melted and cast into moulds.

Zinc, as thus procured, is not pure; it almost always contains iron, manganese, arsenic, and copper. To free it from these, it is again melted and then well stirred with sulphur and fat, the former of which combines with the foreign metals, and leaves the zinc nearly pure, while the latter prevents this metal from being oxidated.

The zinc used in England is chiefly imported, very

little having ever been produced in this Country. It appears that in 1731, the price of zinc amounted to £260 per ton, and soon after, viz. 1738, Mr. Champion of Bristol obtained a patent for manufacturing it from English ores. Up to 1750, he had made about two hundred tons; but the price having fallen very considerably, notwithstanding the English zinc had the preference in the market, he petitioned Parliament for an enlargement of his patent, stating, that, in consequence of the great reduction in the price, he should otherwise be a great loser by his discovery.

Mechanical
Processes.

Platina.

(593.) This is a metal for the discovery of which we are indebted to modern times. Although the ore is not the product of British mines, the best method of working it was the discovery of an eminent British Chemist, the late Dr. Wollaston; and as the reduction of the crude platina to a malleable metal constitutes the principal art connected with it, we do not hesitate to introduce it amongst the manufactures which are generally confined to those of England only. Dr. Wollaston, for many years, kept his mode of operation secret, and he is said to have acquired a considerable fortune in the manufacture of the metal; but a short time before his death, he communicated his process to the Royal Society, and we cannot do better than give the reader the short but important Paper in the author's own words, who commences by observing:

"As from long experience, I probably am better acquainted with the treatment of platina, so as to render it perfectly malleable, than any other Member of this Society, I will endeavour to describe, as briefly as is consistent with perspicuity, the processes which I put in practice for this purpose, during a series of years, without seeing any occasion to wish for further improvement.

Dr. Wollas-
ton's pro-
cess de-
scribed.

"The usual means of giving chemical purity to this metal, by solution in aqua regia and precipitation with sal ammoniac, are known to every Chemist, but I doubt whether sufficient care is usually taken to avoid dissolving the iridium contained in the ore by due dilution of the solvent. In an account which I gave in the *Philosophical Transactions* for 1804, of a new metal, rhodium, contained in crude platina, I have mentioned this precaution, but omitted to state to what degree the acids should be diluted; I now therefore recommend, that to every measure of the strongest muriatic acid employed, there be added an equal measure of water; and moreover, that the nitric acid used be what is called 'single aquafortis;' as well for the sake of obtaining a purer result, as of economy in the purchase of nitric acid.

"With regard to the proportions in which the acids are to be used, I may say, in round numbers, that muriatic acid, equivalent to 150 marble, together with nitric acid equivalent to 40 marble, will take 100 of crude platina; but in order to avoid waste of acid, and also to render the solution purer, there should be in the menstruum a redundancy of 20 per cent. at least of the ore.

"The acids should be allowed to digest three or four days, with a heat which ought gradually to be raised. The solution, being then poured off, should be suffered to stand until a quantity of fine pulverulent ore of iridium, suspended in the liquid, has completely subsided, and should then be mixed with 41 parts of sal am-

Manufac-
tures.

moniac, dissolved in about 5 times their weight of water. The first precipitate, which will thus be obtained, will weigh about 165 parts, and will yield about 66 parts of pure platina.

"As the mother-liquor will still contain about 11 parts of platina, these, with some of the other metals yet held in solution, are to be recovered by precipitation from the liquor with clean bars of iron, and the precipitate is to be redissolved in a proportionate quantity of aqua regia, similar in its composition to that above directed to be used: but in this case, before adding sal ammoniac, about one part by measure of strong muriatic acid should be mixed with 32 parts by measure of the nitromuriatic solution, to prevent any precipitation of palladium or lead along with the ammonio-muriate of platina.

"The yellow precipitate must be well washed, in order to free it from the various impurities which are known to be contained in the complicated ore in question; and must ultimately be well pressed, in order to remove the last remnant of the washings. It is next to be heated, with the utmost caution, in a black lead pot, with so low a heat as just to expel the whole of the sal ammoniac, and to occasion the particles of platina to cohere as little as possible; for on this depends the ultimate ductility of the product.

"The grey product of platina, when turned out of the crucible, if prepared with due caution, will be found lightly coherent, and must then be rubbed between the hands of the operator, in order to procure by the gentlest means, as much as can possibly be so obtained, of metallic powder, so fine as to pass through a fine lawn sieve. The coarser parts are then to be ground in a wooden bowl with a wooden pestle, but on no account with any harder material, capable of burnishing the particles of platina, since every degree of burnishing will prevent the particles from cohering in the further stages of the process. Since the whole will require to be well washed in clean water, the operator, in the latest stages of grinding, will find his work much facilitated by the addition of water, in order to remove the finer portions as soon as they are sufficiently reduced to be suspended in it.

"Those who would view this subject scientifically, should here consider, that as platina cannot be fused by the utmost heat of our furnaces, and consequently cannot be freed, like other metals, from its impurities, during igneous fusion, by fluxes, nor be rendered homogeneous by liquefaction, the mechanical diffusion through water should here be made to answer, as far as may be, the purposes of melting; in allowing earthy matters to come to the surface by their superior lightness, and in making the solvent powers of water effect, as far as possible, the purifying powers of borax and other fluxes in removing soluble oxides.

"By repeated washing, shaking, and decanting, the finer parts of the grey powder of platina may be obtained as pure as other metals are rendered by the various processes of ordinary metallurgy; and if now poured over, and allowed to subside in a clean basin, a uniform mud or pulp will be obtained ready for the further process of casting.

"The mould which I have used for casting, is a brass barrel, $6\frac{3}{4}$ inches long, turned rather taper within, with a view to facilitate the extraction of the ingot to be formed, being 1.12 inch in diameter at top, and 1.23 inch at a quarter of an inch from the bottom, and plugged at its larger extremity with a stopper of steel,

that enters the barrel to the depth of a quarter of an inch. The inside of the mould being now well greased with a little lard, and the stopper being fitted tight into the barrel by surrounding it with blotting paper, (for the paper facilitates the extraction of the stopper, and allows the escape of water during compression,) the barrel is to be set upright in a jug of water, and is itself to be filled with that fluid. It is next to be filled quite full with the mud of platina; which subsiding to the bottom of the water, is sure to fill the barrel without cavities, and with uniformity,—a uniformity to be rendered perfect by subsequent pressure. In order, however, to guard effectually against cavities, the barrel may be weighed after filling it, and the actual weight of its contents being thus ascertained, may be compared with that weight of platina and water which is known by estimate that the barrel ought to contain. A circular piece of soft paper first, and then of woollen cloth, being laid upon the surface, allow the water to pass, during partial compression by the force of the hand with a wooden plug. A circular plate of copper is then placed upon the top, and thus sufficient consistency is given to the contents to allow of the barrel being laid horizontally in a forcible Press.

"The Press which I have generally used for this purpose is represented in plate xlv. fig. 3: it consists of a flat iron bar A B, set edgewise and screwed down by a hook E near its middle, where it would otherwise be liable to bend, to a strong wooden bench C D. The bar is connected, by a pivot at its extremity A, with the lever A F G; an iron rod F H, which turns at its two extremities upon the pivots F and H, proceeds from the lever at F, and, as the lever descends, propels forward the carriage I, which slides along the bar. A stopper or block being placed in the vacant space I K, the carriage communicates motion to the cradle *k l m*, which is also made to slide along the bar, and carries the barrel N, which lies upon the cradle, straight against the piston O O, which rests by its end against P, a projection in the further extremity of the bar.

"The weight which in this Machine, when the angle of the lever's elevation is small, will keep the power, applied vertically at the extremity of the lever, in equilibrium = that power $\times \frac{AG \times FH}{AF(AF + FH)} \times \cotan.$ of the

angle of the lever's elevation; which expression, in the case of the Press actually used, becomes, power $\times 5$, $\cotan.$ of the angle of the lever's elevation. This expression, at an elevation of 5° , becomes nearly $60 \times$ power, and at an elevation of 1° becomes nearly $300 \times$ power; and when the lever becomes horizontal the multiplier of the power becomes *quasi* infinite. This explanation will be sufficient to show the mechanical advantage with which, by means of this Press, the weight of the operator, acting on the end of the lever, will be made to bear against the area of the section of the barrel, a circle a little more than an inch in diameter.

"After compression, which is to be carried to the utmost limit possible, the stopper at the extremity being taken out, the cake of platina will easily be removed, owing to the conical form of the barrel; and being now so hard and firm that it may be handled without danger of breaking, it is to be placed upon a charcoal fire, and there heated to redness, in order to drive off moisture, burn off grease, and give to it a firmer degree of cohesion.

"The cake is next to be heated in a wind furnace,

Mechanical
Processes.

Press employed in
the process
Pl. xlv.
Fig. 3.

Manufac-
tures.

and for this purpose is to be raised upon an earthen stand about $2\frac{1}{2}$ inches above the grate of the furnace, the stand being strown over with a layer of clean quartzose sand, on which the cake is to be placed, standing upright on one of its ends. It is then to be covered with an inverted cylindrical pot, of the most refractory crucible ware, resting at its open end upon the layer of sand, and care is to be taken that the sides of the pot do not touch the cake.

"To prevent the blistering of the platina by heat, which is the usual defect of this metal in its manufactured state, it is essential to expose the cake to the most intense heat that a wind furnace can be made to receive, more intense than the platina can well be required to bear under any subsequent treatment, so that all impurities may be totally driven off, which any lower temperature might otherwise render volatile. The furnace is to be fed with Staffordshire coke, and the action of the fire is to be continued for about twenty minutes from the time of lighting it, a breathing heat being maintained during the last four or five minutes.

"The cake is now to be removed from the furnace, and, being placed upright upon an anvil, is to be struck, while hot, on the top, with a heavy hammer, so as at one beating effectually to close the metal. If in this process of forging the cylinder should become bent, it should on no account be hammered on the side, by which treatment it would be cracked irremediably; but must be straightened by blows upon the extremities dexterously directed, so as to reduce to a straight line the parts which project.

"The work of the operator is now so far complete, that the ingot of platina may be reduced, by the processes of heating and forging, like that of any other metal, to any form that may be required. After forging, the ingot is to be cleaned from the ferruginous scales, which its surface is apt to contract in the fire, by smearing over its surface with a moistened mixture of equal parts, by measure, of crystallized borax and common salt of tartar, which, when in fusion, is a ready solvent of such impurities, and then exposing it, upon a platina tray, under an inverted pot, to the heat of a wind furnace. The ingot, on being taken out of the furnace, is immediately to be plunged into dilute sulphuric acid, which in the course of a few hours will entirely dissolve the flux adhering to the surface. The ingot may then be flattened into the leaf, drawn into wire, or submitted to any processes of which the most ductile metals are capable.

"The perfection of the methods above described for giving to platina complete malleability, will best be estimated by comparing the metal thus obtained, in respect of its specific gravity, with platina which has undergone complete fusion; and by comparing it, in respect of its tenacity, with other metals possessing that quality in the greatest perfection.

Specific
gravity of
platina.

"The specific gravity of platina, drawn into fine wire from a button, which had been completely fused by the late Dr. E. D. Clarke with an oxyhydrogen blowpipe, I found to be 21.16. The aggregate specific gravity of the cake of metallic mud, when first introduced into the barrel, exclusively of moisture, is about 4.3; when taken from the Press, is about 10; that to which the cake fully contracted, on being taken out of the wind furnace before forging, is from 17 to 17.7. The mean specific gravity of the platina after forging is about 21.25, although that of some rods after being drawn is 21.4; but that

of fine platina wire, determined by comparing the weight of a given length of it with the weight of an equal length of gold wire drawn through the same hole, I find to be 21.5; which is the maximum specific gravity that we can well expect to be given to platina.

Mechanical
Processes.

"The mean tenacity, determined by the weights required to break them, of two fine platina wires, the one of $\frac{1}{3000}$ the other of $\frac{1}{3850}$ of an inch in diameter, reduced to the standard of a wire $\frac{1}{10}$ th of an inch in diameter, I found to be 409 pounds; and the mean tenacity of 11 wires, beginning with $\frac{1}{4500}$ and ending with $\frac{1}{25000}$ of an inch, reduced to the former standard, I found to be 589 pounds; the maximum of these 11 cases being 645 pounds, and the minimum 480 pounds. The coarsest and the finest wire which I tried present exceptions; since a wire of $\frac{1}{1500}$ of an inch gave 290 pounds, and a wire of $\frac{1}{30000}$ of an inch, 190 pounds. If we take 590 pounds, as determined by 11 consecutive trials, to be the measure of the tenacity of the platina prepared by the processes above described, and consider that the tenacity of gold wire, reduced to the same standard, is about 500, and that of iron wire 600 we shall have full reason to be satisfied with the processes detailed in the present Paper, by which platina has been rendered malleable."—*Phil. Trans.* for 1829.

Tenacity of
the wire.

Alloys of Metals. Brass.

(594.) This compound metal was known to the Ancients, as we find by many parts of the Old Testament, as well as from various ancient Historians, but it does not appear that they were properly acquainted with its nature or composition. They considered it as a particular kind of copper, found native in the mines in which zinc and copper seem to have been found in the proper proportions for its production: it was denominated by the Greeks *Orichalcum*, i. e. *Æs montanum*, a particular sort. *Æs Corinthiacum* is generally supposed to have been a mixture of gold, silver, and copper, metals with which Corinth abounded, melted down together at the burning of this city by the Romans in A. C. 496. At what time the actual constitution of brass became known, is not stated with any certainty, but it appears unquestionable, that in early times it was exceedingly valuable, from the supposition of its being a rare and distinct metal, or particular species of copper; it being stated that as the mine in which it was obtained failed, it was supposed to be impossible to obtain it any other way, and that in value it held a middle place between gold and silver.

History of
brass.

After the real nature of brass became known in Europe, the Art of making it was principally confined to Germany, where the processes were kept very secret; and the first brass made in England was by persons of that nation, Jacob Momma and Daniel Demetrius, who, about the year 1649, established a brass work at Esher in Surrey, at a cost of £6000, but not meeting with encouragement, they were ruined by their undertaking, and the works were discontinued. Others, however, were afterwards established, and the operators employed English ore of zinc, which had been hitherto transported merely as ballast, but the copper was imported from Sweden till the revival of our own copper works in 1690.

The ore of zinc which is used in combination with copper to constitute brass, is called by the English calamine; it is of various colours, most commonly greyish with a cast of brown, a yellowish and a pale red. Some pieces are of

Ores of
zinc, their
colour, &c.

Manufac-
tures.

a gold yellow, others, white, blue, dark brown, &c. Several of the larger masses, when broken, exhibit all these colours, and in some places one colour, and in others a different colour is esteemed the best, so that mere colour seems to be little or no guide. England, Germany, and many other Countries afford calamine in great abundance: it is met with sometimes at considerable depths, and sometimes near the surface; in continued horizontal strata, in perpendicular veins, in detached masses bedded in different kind of earths, or intermingled with the ores of lead, and sometimes of other metals. It is plentiful in several lead mines in England, particularly about the Mendip hills near Wrington, in Somersetshire. Lead ores likewise frequently break up among the courses or strata of calamine. At Goslar, it is naturally intermixed, in very small molecularæ, with a compound ore containing lead, copper, and other metals; the zinc separates during the fusion of the ore, partly rising and running off in its metallic form into a reservoir made for this use, and partly subliming in flowers to the upper part of the furnace. Swedenborg informs us, that these flowers, called *cadmia* or *cadmia formacum*, are employed for the same purposes as the fossil calamine in other places, and that a less proportion of them is sufficient.

The English calamine is said to be found by the workmen to answer better than some which had been brought from Dantzick; by Margraff, to be richer in zinc than the foreign sorts which he examined; but Swedenborg states it to be of a worse quality than those of most other Countries, on account of its admixture with lead. When lead is combined with the ore, the larger masses are picked out by hand, and the smaller separated by washing. In this operation, the lighter parts are first washed away in the usual manner in an enclosure of boards by a stream of water passing through. The rest is then put into strong wire sieves, and well shaken in a vessel of water, by which means the more ponderous lead ores fall to the bottom and are thus separated; but where the lead ore is in too minute particles, or too intimately mixed to be separated by this process, upon calcining the mineral with a moderate fire, it runs into masses, which freely subside in the water from the purer calamine.

Method of
calcining
the ore.

It is customary to calcine all the sorts of calamine before they are employed for the making of brass. In some places the ore is piled in conical heaps of twelve feet diameter and six feet high, with layers of fuel intermixed. Such a pile burns about twenty-four hours. In other places the calcining is effected in a furnace built for the purpose, in which the ore is excluded from immediate contact with the fuel. In England, the calcining furnace resembles a baker's oven, with an apartment on one side for the fuel, wood or pit-coal; the partition betwixt the two chambers is open at top for suffering the flame to pass over and reverberate upon the mineral. The capacity of the furnace is such as to receive a ton of calamine spread four or five inches thick. The process lasts four, five, or six hours; the ore being occasionally stirred and turned with long iron rakes.

The marks of sufficient calcination are, the calamine being of a whitish colour, and easily reducible into a very fine powder. It loses in this operation from one-third to one-half its weight. A large quantity of flowers of divers colours is found adhering to the mouth of the furnace. These, though not applied to any considerable

use, appear to be the same with the *pompholyx* of the Ancients, and the celebrated *cadmia* of Goslar. It is stated that calamine not sufficiently calcined does not mix with copper; and that when over calcined, it makes the brass turn out brittle, and that it does not give the true tincture in either case. Swedenborg states, that the principal use of this process is, to render the calamine sufficiently pulverable; others state that calcination is never needful, unless where the mineral contains any sulphureous or arsenical matter.

The calcined calamine is next reduced to powder by iron mallets or by mills. In Sweden, it is said that the powder is ground between millstones in the same manner as corn.

The zinc contained in calamine is in a state of calx, and requires to be revived by the admixture of inflammable substances, in order to its uniting with copper. The inflammable matter generally made use of is charcoal. The harder sorts of charcoal are said to answer better for this use than the soft, occasioning the yield of zinc to be greater. The quantity of charcoal is usually equal to that of the calamine, but Cramer observes, that though an equal *weight* is necessary in small essays, in the larger works an equal *measure* is sufficient: the quantity of charcoal, on this supposition, is from one-sixth or a little less, to somewhat more than one-fourth of the calamine, according to their different gravities.

It is supposed necessary that the calamine and charcoal be reduced into very fine powder, especially the former, and that they be well mixed together. In some places, the mixture is performed by means of rakes drawn several times backwards and forwards through the powders, which are moistened with a little water or urine; in others, they are circumagitated together; at Goslar, a little alum and common salt are added, which are said to give the brass a better colour in the first fire.

It is also supposed necessary that the copper to be intermingled with the foregoing composition be pure and of a good quality, and that otherwise the zinc will not easily unite with it. Copper-plates have been generally made use of. These are stratified with the mixtures in large crucibles, a part of the mixture making the lower stratum, and of the copper the upper: the quantity of metal placed on the top, is double to that in the bottom of the crucible.

In some places the copper is reduced into grains, and uniformly mingled with the ore and charcoal; by this management it is said to gain an increase of one-tenth more than the plates usually do. The apparatus for granulating the copper is a brick cistern four or five feet deep, full of water, covered with a brass plate, in the middle of which is an aperture of half a foot. Into this is fitted a little vessel perforated with a number of very small holes secured with Stourbridge clay; the melted copper is poured into this vessel with iron ladles, and falling through the minute holes into the cold water, congeals into granules, without any explosion or danger to the bystanders. If the water is suffered to grow hot, the metal falls liquid to the bottom and runs into plates; to prevent this, a stream of cold water is kept continually passing through the cistern. The quantity of copper granulated at a time is one ton. Swedenborg, tom. iii. Ann. 1734.

The proportion of this calcined ore and copper for forming the brass varies in different works from 40 to 61. The two, combined in these proportions, are placed in crucibles made of Stourbridge clay, mixed

Mechanical
Processes.

Russia leather.

Manufactures.

Pl. xlv.
fig. 4.

with an equal quantity of the same clay calcined, or old pots powdered. Their capacity is such as to receive from 5 to 12 pounds of copper, with the requisite proportion of the calamine, and a furnace will receive several such crucibles. See plate xlv. fig. 4. The fire is at first gentle and increased by degrees till the metal comes into fusion, in which state it is kept for some time that the copper and zinc may be more perfectly united. To promote this effect, the crucibles are in some places occasionally shaken. The fire is continued from 9 to 16 hours, in most places 11 or 12. In Sweden, it has been found that with 14 hours the brass proves better than with 12. The fuel is applied twice, the first quantity being consumed in 9 hours, the other in 5 hours. In some works, if not in all, when the crucibles are put in the furnace, the spaces between them are filled up with damp fern, cut into cakes like hay from a rick, with which the crucibles likewise are covered. Above this are put two bushels of coal, and the furnace is covered with an iron plate a little way at first, and when the heat is strong, the whole way, a small quantity of coal is occasionally added and the clinkers are removed. The appearance of yellow fumes is a sign that the process is completed.

After sufficient fusion, the metal is lifted with its crucible by a pair of tongs formed for the purpose, and the brass in each is poured into one large crucible placed in the furnace to receive it; here it is carefully skimmed and afterwards cast into plates in moulds.

Description of the moulds. The mould consists of two flat stones enclosed in an iron frame joined at one side by a kind of hinge, with screws to raise or lower them occasionally. They are elevated at one end when the metal is to be poured betwixt them, that it may fill up the whole vacuity, and then they are set horizontally to cool.

These stones are about the size of grave-stones, and weigh each a ton or more. They must be annealed some hours before the plates are cast on them, otherwise the metal will fly and likewise endanger their breaking. In Sweden they are coated with clay; in England with coal and tallow. The workmen have many pair of them in readiness, because after three days' working they become *weary*, and require to be coated anew.

The stones most proper for this use are of the kind called *Saxa arenaria*. They have many small shining particles like spar which continue after long use. They should neither be very hard nor very soft; if too hard, they do not hold the clay, if too soft, they crack or shiver by the heat of the metal. The better sorts last four or five years.

The stones for this purpose are said to have been formerly imported to us from Holland and St. Maloes, but those now used are found in the mountainous parts of Cornwall. They are called in some places *Britain stones*, and are supposed to be the produce of this Country only.

Trials have been made at Hamburg and in Sweden, for substituting iron plates for the stones. The inconveniencies were, that the iron could not be coated with clay; that when not coated, the brass congealed without running to the further end of the mould; that it likewise proves porous and very brittle. Iron plates are nevertheless made use of in the Tyrol.

After the stones have been used for some time, their colour is changed from a grey to a reddish or copper hue, the shining specks only remaining. The crucibles are tinged throughout of a blue colour.

The plates of brass as first taken out of the mould are brittle, and in order to render them malleable, they must be annealed for some hours in an annealing furnace; the brass is then fit for the market.

The peculiarities of brass as compared with copper are, that it is lighter, harder, and more sonorous than pure copper. It melts more easily, but does not scorify so soon in a moderate heat. It is less ductile, and malleable only whilst cold. Heated a little, it cracks, ignited, it falls to pieces under the hammer, cooled in air at the ordinary temperature, it remains brittle as when hot, but cooled more slowly or annealed it becomes malleable; if heated beyond a cherry red, its zinc begins to exhale.

(595.) *Brass by cementation*.—Brass is generally made by fusion as described in the preceding part of this article, but it may also be obtained by cementation after a process similar to that by which iron is converted into steel.

This process is not, however, very generally understood. The following experiments, therefore, with which the writer has been furnished from the MSS. of an ingenious metallurgist, now no more, will be interesting.

The simplest kind of experimental cementing furnace for brass is one divided vertically by two partitions into three spaces, the fire being made in the two sides, and the metal, &c. deposited in the centre. This central part, although thus fixed in its place, is still denominated a crucible. The bottom of it is covered to about half an inch with powdered charcoal lightly pressed down. On this some copper in the form of bars or plates is laid, which is not intended to be converted into brass, and two large plates of copper are so placed as to line the sides of the crucible: the bars to be cemented or converted into brass are then placed in the middle. The crucible is then nearly filled up with a mixture of calamine and charcoal gently pressed down, but not very close, and then more powdered charcoal spread upon it; above this, thinner plates of copper are laid flat so as entirely to cover the materials, and two other large plates over them, and, lastly, the whole is covered with charcoal powder.

The following are the results of the several experiments alluded to.

Weight of Copper, Calamine, and Charcoal.

	lbs.	oz.	drs.
Copper two side plates	4	6	0
Two plates on the top	0	9	2
Three essay bars, No. 1	0	2	6
ditto No. 2	0	4	0
ditto No. 3	0	4	12
The other plates and bars	4	13	0
	10	7	4

	lbs.	oz.
Calamine	7	112
Charcoal	2	32

	144
Omitted of the mixture } for want of room. }	19

125 ounces the weight of mixture employed.

The charcoal and calamine being reduced proportionally, the real quantity employed was,

	oz.	drs.
Of charcoal	27	1½
Of calamine	97	3½

Mechanical Processes.

Brass formed by cementation.

Manufac-
tures.

A cover was luted on the crucible, having a hole in it to be opened occasionally for taking out the essay bars, and another into which a tube was inserted for allowing an exit to moisture and elastic vapours; a piece of copper was laid on the top of the pipe for discovering whether any flowers of zinc would arise.

A gentle fire was made in each of the side fire-places for about an hour to dry the luting, &c., after which a stronger fire, excited during the greater part of the time with bellows, was continued for eight hours, and then suffered gradually to decay.

Experiment 1.

At the end of the first two hours (exclusively of the hour of weak fire) the bar No. 1 was taken out. It appeared scarcely visibly red hot at the lower part, had undergone no sensible change, and had gained no increase of weight.

Experiment 2.

After two hours longer fire, the bar No. 2 was found red hot three-fourths of its length. The lower part was tinged externally yellow, and in breaking it the colour of the copper seemed in some measure gone off. Increase of weight barely 1 dw.

Experiment 3.

After two hours longer, the third bar appeared red hot all over; when cold, yellow externally to nearly the top. The calamine seemed to have penetrated quite into the middle, where it discovered itself in pale yellowish specks and streaks.

Increase of weight $1\frac{1}{2}$ drs. = about $\frac{1}{3}$.

Experiment 4.

After the fire had continued about two hours longer, and the whole had become cold, the furnace was uncharged. The two upper plates were found unchanged and scarcely sensibly increased in weight. All the others were in part tinged yellow externally and to a considerable depth.

	lbs.	oz.	drs.
Weights of the metal exclusively of the two upper plates and first essay bar.	Put in	9 11 12	
	Taken out.	10 3 6 $\frac{1}{2}$	
	Increase . . .	0 7 10 $\frac{1}{2}$	

Experiment 5.

Some of the pieces which appeared the most tinged, and which were externally of a very beautiful colour, in weight 6 ounces 13 drachms, were fused in a crucible with some charcoal powder. No sensible loss of weight. The metal appeared to the eye paler than common brass. On the rub-stone, it discovered more of a copper hue. It hammered well without cracking.

Experiment 6.

The rest of the copper with the two upper plates and bar No. 1, amounting in all to 10 pounds 7 ounces 12 drachms, was cemented a second time with the same mixture which now weighed 6 pounds 9 ounces 8 drachms = 105 $\frac{1}{2}$ ounces; 4 ounces more charcoal powder were mixed with it, and 2 other ounces were laid on the top. The two upper plates were turned upside down, the same side put next the crucible as before. The furnace was covered with its dome and chimney, and the

fire kept up 11 hours without blowing. After this second cementation, Mechanical Processes.

The metal weighed. . . . 10 lbs. 8 oz. increase 4 drs.

The mixture weighed. . . 6 lbs. 12 oz. loss 3 $\frac{1}{2}$ ozs.

Total increase 7 oz. 14 $\frac{1}{2}$ drs. = nearly $\frac{1}{18}$ calamine.

Examination in a blast furnace of the mixture remaining after the preceding cementation.

Experiment 1. (Perfect fusion.)

Upon 2 ounces of the mixture slightly pressed down, was laid 1 ounce of the twice-cemented metal in thin slips in a black lead crucible, which was filled up with charcoal in coarse powder and covered with a slip of brick. The metal was poured into a mould, some grains were collected by washing.

Weight of the whole 1 ounce 3 $\frac{1}{8}$ drachms.

Increase $\frac{7}{8}$ of the mixture or $\frac{7}{8}$ of the metal.

This experiment was repeated with the addition of 1 ounce more charcoal powder to the mixture, besides that on the top furnace which issued between the crucible and its cover: the charcoal seems to have burned away considerably; the increase was $\frac{1}{8}$ of a drachm less than before.

Experiment 2. (Imperfect fusion.)

The same was repeated in a crucible formerly used close luted. No fumes appeared; the metal melted imperfectly.

Increase of weight 2 $\frac{1}{2}$ drachms.

Experiment 3. (Perfect fusion.)

Four ounces of the metal were stratified with the same weight of the mixture mingled with 1 ounce fresh charcoal powder. The metal was melted with a pretty strong heat and poured into an ingot mould.

Increase of weight 13 drachms or $\frac{1}{8}$ of the metal.

Experiment 4. (Imperfect fusion.)

Mixture 4 ounces, metal 6 ounces. Great part of the mixture was put into the bottom of the crucible formerly used, and the copper slips laid thereon, with the rest of the matter intermixed. Fumes issued in considerable quantity, some of the slips melted, others did not, but just united.

Increase scarcely 13 drs. = $\frac{1}{8}$ of mixture.

Experiment 5. (Perfect fusion.)

Mixture 2 ounces metal, 4 ounces fresh charcoal, 1 ounce metal placed all on the top, with charcoal in pretty fine powder over it, close luted.

When the crucible came to a strong red heat, the cover was thrown off. Greatest part of the metal melted, so as to be poured into an ingot mould, which, with some grains collected by washing, weighed 4 oz. 5 $\frac{1}{2}$ drs.

Increase $\frac{1}{8}$ of mixture, or $\frac{5}{8}$ of metal.

(596.) *Proportion of the Component Parts in various Compound Metals.*

Gun metal 1 tin + 10 copper, or 1 tin + 2 zinc + 16 brass.

Bell metal. . . . 6 copper + 2 tin.

Specular metal. . . 7 copper + 3 zinc + 4 tin.

Bronze 7 copper + 3 zinc + 2 tin.

Bath metal. . . . 4 $\frac{1}{2}$ zinc + 16 brass.

Pinchbeck 16 zinc + 5 copper.

ditto 1 brass + 2 copper.

Princes metal. . . 3 copper + 1 zinc.

Manufactures.

Prince's metal . . 4 copper + 2 zinc.
 British tutania . . 4 copper + 4 tin + bismuth + 4 regulus of antimony to be combined with melted tin at discretion.
 Ditto 16 copper + 16 tin + 32 regulus of antimony.
 Queen's metal . . 9 tin + 1 bismuth + 1 antimony + 1 lead or 100 tin + 8 regulus antimony + bismuth + 4 copper.
 White metal . . . 10 lead + 6 bismuth + 4 regulus antimony or 10 tin + 8 brass + 2 regulus antimony.
 Hard white ditto, 2 brass + 3 zinc + 10 tin.
 Blanched copper, 16 copper + 1 neutral arsenical salt.
 Printer's types . . 10 lead + 2 antimony.
 Small type and } 9 lead + 2 antimony + 1 bismuth
 stereotype plates. } or 16 lead + 4 antimony + 1 tin.
 Common pewter, 7 tin + 1 lead + $\frac{3}{4}$ copper + $\frac{1}{8}$ zinc.
 Hard pewter . . . 12 tin + 1 regulus antimony + $\frac{1}{2}$ copper.
 Best pewter . . . 100 tin + 17 regulus antimony.
 Solder common . 2 lead + 1 tin.
 Ditto soft 1 lead + 2 tin.
 Do. for steel joints, 19 silver + 1 copper + 2 brass.
 Ditto silver . . . 19 silver + 1 copper + 10 brass.
 Ditto for plating, 1 brass + 2 silver.
 Ditto gold 12 pure gold + 2 silver + 4 copper.
 Standard silver, 37 silver + 3 copper.
 Ditto gold 11 gold + 1 copper.
 Jewellery gold . . $8\frac{3}{4}$ copper + $\frac{1}{2}$ silver + 1 gold.
 Common gold . . 3 copper + 1 old brass + $\frac{1}{4}$ tin.
 Menheim gold . . 7 copper + 3 brass + $1\frac{1}{2}$ tin.
 Gilding metal . . 4 copper + 1 brass + $3\frac{1}{2}$ tin.

Works for the Production of Acids, Salts, Pigments, and other Substances.

Alum Works.

Composition of alum.

(597.) The saline substance denominated alum by the Moderns is found by analysis to consist of

Sulphuric acid	34.33
Alumina	10.86
Potash	9.81
Water	45.00
	100.00

or, according to the atomic theory,

Sulphuric acid 4 + alumina 3 + soda 1 + water 25.

It is of extensive use in the Arts, particularly in dyeing, printing, and medicine.

History of alum.

This is not, however, the same substance which passed under the name of alum with the Ancients, the latter having been merely a vitriolic earth, formed naturally in some mines. Both alum and vitriol are neutral salts or saline substances, strongly resembling each other. Both contain the same acid; both have strong astringent qualities; they are both also frequently found in the same place, and obtained from the same mineral, and they both may be applied in the same manner and for like purposes. The difference is that vitriol is combined with a metallic earth, and alum with that of a white earth, called, therefore, alum earth.

The alum of the Ancients was a natural formation, and we, accordingly, find no account of alum and vitriol works in any Greek or Roman author, except what is mentioned by Pliny, who states that blue vitriol was

VOL. VII.

made in Spain by the process of boiling; and this circumstance he considers as the only one of its kind, and so singular, that he was of opinion no other salt could be obtained in the same manner. Besides, every thing related by the Ancients of their alum agrees perfectly with natural vitriolic substances; but to describe them all might be difficult; for they do not speak of pure crystals, but of saline bodies, which Nature herself exhibits in various ways, and under a variety of forms; and every small difference in the colour, the exterior or interior conformation, however accidental, provided it could be clearly distinguished, was to them sufficient to make a distinct species, and to induce them to give it a new name.

The celebrity which the ancient alum had, as a substance extremely useful in dyeing and medicine, was entirely forgotten when the alum of the Moderns became known; but this celebrity was again revived when it was discovered that real alum could be made from vitriolic minerals, or that where the latter are found there are generally minerals which abound with it. In many of these places alum works have, in the course of time, been erected; and this circumstance has served in some measure to give rise to the opinion that the alum of the Ancients and that of the Moderns are the same salt; because, where the former was found in ancient times, the latter has since been procured by a chemical process.

(598.) The first invention of the process of procuring the modern alum by artificial means is not known, but it appears to have originated in the East some time soon after the XIIth Century. In the XVth Century there were alum works in the neighbourhood of Constantinople, and about that period such works appear to have been first introduced into Italy and other Countries of Europe. The celebrated alum works of Tolfa, about six miles from Civita Vecchia, in the territories of the Pope, are stated by some Italian authors to be the first works of the kind established in Europe; and however this may be, they are the oldest carried on at present.

Here the ore is blown up with gunpowder: it is separated from the pieces of the rock that adhere to it; it is calcined in furnaces, nearly in the same manner as lime is burned; in six or seven hours being sufficiently calcined and friable, it is then taken out, and laid on pavements of a long shape, surrounded with walled trenches; on these it is laid in heaps of a moderate height, which are watered for forty days with water from the trenches. The ore being thus decomposed, it is boiled in large caldrons, and when the water is saturated to a certain point, it is poured into the crystallizing pans, where, after it is cold, it deposits the alum in large crystalline masses.

At Solfa terra, near Puzzuola, the alum is obtained by a different process, Nature herself assisting materially in the operation. Sulphurous fumes and sulphuric acid are continually issuing from little crevices in the volcanic soil of this place, the former of which deposit a concrete sulphur; the second gradually penetrates the ancient lavas, which are of an argillaceous nature, combines with their alumina, and thus forms an alum ore, which afterwards affords, by lixiviation and crystallization, a very pure alum.

The first alum works in England were established at Whitby in Yorkshire, by Sir Thomas Chaloner, who was excommunicated by Pope Pius II. for so doing, his Holiness having assumed the right of exclusively sup-

Mechanical Processes.

Formation of artificial alum

at Tolfa,

at Solfa terra.

Manufac-
tures.

Usual pro-
cess with
pyritous
ores.

Yorkshire
process as
described
by Mr.
Winter.

plying the alum of Europe. Notwithstanding this sentence, however, the work continued, and still continues to be the largest of the kind in England; there are, however, larger works, as the Hurlett mine near Glasgow.

Nearly all the alum works of Europe, with the exception of the two just mentioned in Italy, obtain the salt from pyritous ores. In the process followed in the latter cases the first step is the acidification of the sulphur, and the formation of the sulphate of alumina; to effect which the common practice is to roast the ore as soon as it is obtained from the mine. This is done by laying it in large heaps and burning it with wood or thorns till it is white, or it is sometimes done by rearing a pile of ore and of coal in alternate layers, and kindling it at the bottom. When it is sufficiently calcined, it is put into a pit, where it is macerated with water for eight or ten hours, the lie is then drawn off into large cisterns or reservoirs, and a fresh quantity of water is put on the ore in the pit. This, after some time, having acquired a sensible but weaker impregnation than the former, is likewise run off into the cistern. From this it is conveyed into pans, where it is kept boiling for twenty-four hours. There is then added to it a lie prepared from kelp; and after some time, the liquor is drawn off into a vessel, in which its impurities may subside. When clear, it is run into coolers, where it is allowed to remain four days and nights, and a quantity of putrid urine is sometimes added, in the proportion of eight gallons to a ton of liquor. When the alum crystallizes, the residual liquor is removed, and mixed with the liquor obtained from a fresh quantity of materials, which is to be evaporated. The crystallized alum is then washed, and the water allowed to drain from it; it is then melted in a pan, and while in its liquid state is conveyed into tuns, in which it is allowed to remain about ten days, during which it becomes fully concremented. The tuns are then unhooped, and the large masses of alum are broken down and stowed for market. A particular account of this process, observed at Whitby and other works, is given by Mr. Winter, in Nicholson's *Journal*, vol. xxv., from which it appears that the stratum of aluminous schistus impregnated with pyrites, in the Yorkshire district, is about twenty-nine miles in width, and is covered with strata of alluvial soil, sandstone, ironstone, shell, and clay. The alum schist is generally found disposed in horizontal laminæ. The upper part of the rock is most abundant in sulphur, so that a cubic yard taken from the top of the stratum is five times more valuable than the same bulk one hundred feet below.

(599.) According to Mr. Winter's statement, the expense of digging and removing to a distance of 200 yards one cubic yard of the schistose rock, is about sixpence halfpenny, and a man can earn from 2s. 6d. to 3s. a day. The rock broken into small pieces is laid on a horizontal bed of fuel, composed of brushwood, &c. When about four feet in height of the rock is piled on, fire is set to the bottom and fresh rock is continually poured upon the pile. This is continued until the calcined heap be raised to the height of 90 or 100 feet. Its horizontal area has also been progressively extended at the same time, till it forms a great bed nearly 200 feet square, having about 100,000 yards of solid measurement. The rapidity of the combustion is allayed by plastering up the crevices with small schist moistened; but notwithstanding this precaution, a great deal of sulphuric or sulphurous acid is dissipated. 130 tons of calcined

schist produce on an average one ton of alum. This result has been deducted from an average of 150,000 tons. Mechanical Processes.

The calcined mineral is digested in water contained in pits usually measuring about 60 cubic yards. The liquid is drawn off into cisterns, and afterwards pumped up again upon fresh calcined *mine*. This is repeated until the specific gravity becomes 1.5. The half-exhausted schist is then covered with water to take up the whole soluble matter. The strong liquor is drawn off into settling cisterns, in which the sulphate of lime, iron, and earth are deposited. At some works, the liquor is boiled, which aids in purification. It is then run into leaden pans ten feet long, four feet nine inches wide, two feet two inches deep at one end, and two feet eight inches at the other. This slope admits of their being easily emptied. Here the liquor is concentrated at a boiling heat. Every morning the pans are emptied into a settling cistern, and a solution of muriate of potash, either pretty pure from the manufacturer's, or crude and compound from the soap boiler's, is added. The quantity of muriate necessary is determined by a previous experiment in a basin, and is regulated for the workmen by the hydrometer. By this addition, the pan liquor, which had acquired a specific gravity of 1.4 or 1.5, is reduced to 1.35. After being allowed to settle for two hours, it is run off into the coolers to be crystallized. At a greater specific gravity than 1.35, the liquor, instead of crystallizing, would, when it cools, present us with a solid magma resembling grease. Urine is occasionally added to bring it down to the proper density.

After standing four days, the mother-waters are drained off, to be pumped into the pans on the succeeding day. The crystals of alum are washed into the tub and drained. They are then put into a lead pan with as much water as will make a saturated solution at the boiling point. Whenever this is effected, the solution is run off into casks. At the end of ten or sixteen days, the casks are unhooped and taken apart. The alum is found exteriorly in a solid cake, but in the interior cavity in large pyramidal crystals, inserted successively into one another. This last process is called *roching*. Mr. Winter says, that 22 tons of muriate of potash will produce 100 tons of alum, to which 31 tons of the black ashes of the soap boiler, or 73 of kelp, are equivalent. Where much iron exists in the alum ore, the alkaline muriate, by its decomposition, gives birth to an uncrySTALLIZABLE muriate of iron.

The alum manufactured according to the preceding mode is a sulphate of alumina and potash. There is another alum which exactly resembles it; this is a sulphate of alumina and ammonia. Both crystallize in regular octoedrons, formed by two four-sided pyramids joined base to base. Alum has an astringent, sweetish taste. Its specific gravity is about 1.71. It reddens the vegetable blues. It is soluble in 16 parts of water at 60°, and three-fourths of its weight at 212°. It effloresces superficially on exposure to air, but the interior remains long unchanged. Its water of crystallization is sufficient at a gentle heat to fuse it. If the heat be increased, it froths up and loses fully 45 per cent. of its weight in water. The spongy residue is called burned or calcined alum, and is used by surgeons as a mild escharotic. A violent heat separates a great portion of its acid.

Mr. Winter is very averse from the use of urine in this manufactory, observing that at the works of Lord Dundas, and those of Messrs. Baker and Co., which approach

Manufac-
tures.

nearest in their process to true chemical principles, they use no urine. The alum liquor is always purified previous to its being used. They use no alkali generally, but crystallized muriate of potash; greater economy is observed in the consumption of fuel, and the result is a product of alum considerably larger in a given time, and of better quality than can be produced on the old plan.

The kelp used is obtained by burning the sea wrack in kilns, at a great many places on the coast of England, Scotland, &c., but it is a very inferior alkali in an alum manufactory; it contains about 47 of soluble salts, and 53 charcoal, sand, and dirt; the salts are muriate of soda and sulphate of soda. The refuse of soap boiler's lees are burned in a kind of oven, and sold under the name of black ashes. The composition of these ashes is about 90 soluble salts and 10 of charcoal and earths. The salts contain muriate of soda and potash, sulphate of potash, and muriate of lime and magnesia. Mr. Winter says he always found great difficulty in producing alum by the muriate of soda, and never could form alum in any way by means of pure soda. The muriate and sulphate of potash are the only alkalis that can be used to advantage in the composition of alum.

The following are the results of Mr. Winter's experiments on the quantity of different alkalis required to make 100 tons of alum; viz.

22 tons of muriate of potash, 100 tons alum.

31 ditto black ashes ditto.

70 ditto kelp ditto.

Nicholson's *Journal*, vol. xxv.

In 1828, Mr. Strachan took out a patent for an improvement in the method of manufacturing alum, for a description of which we refer the reader to vol. liv. of the *Repertory of Arts*.

Charcoal Works.

Manufac-
ture of
charcoal.

(600) Charcoal, as an important article in many processes connected both with the Arts and Manufactures, may, it is presumed, be with propriety introduced into this section of the Treatise, although the place of manufacture or preparation of it is not generally called a charcoal work.

For common purposes the usual way of charring wood is in what are called *charring pits*. The wood is first cut into lengths of about three feet, and then piled on the ground in a circular form; three, four, or more faggots, or, as they are called, cords of wood, making what is called a pit. These are covered with fern, straw, &c., or kept down by earth or sand to support the fire, giving it air by vent holes as may be found necessary or convenient; but this mode of charring is uncertain in its operation, and in every respect defective for the purpose of making good charcoal, and, consequently, it is when thus prepared very unfit for the manufacture of gunpowder, which requires all its ingredients to be of the most perfect kind.

For the latter purpose, therefore, in particular, the method now adopted consists in distilling the wood in iron cylinders, not much unlike the method practised in our gas works for the distillation of the coal. For this purpose, iron cylinders or retorts are employed, and the wood to be charred is cut into pieces of about nine inches in length, and then put into the cylinder, which is placed horizontally. The front opening or mouth of the retort is then closed, and at the further end are pipes leading into casks. The fire being made under the

cylinder in the proper furnace, the pyroligneous acid, attended with a large portion of carburetted hydrogen gas, comes over. The gas escapes while the liquor descends through the pipes, and is collected in the casks, and the fire is kept up till no more liquor or gas will come over. This, it is evident, is a more eligible method than the former, indeed the only proper one, and the difference in the strength of powder made from the two sorts of charcoal is such, that since the Government powder has been made with it, the charges of powder for the same piece of ordnance are said to have been reduced one-third. We suspect, however, that some of this reduction is due to the more accurate boring of the gun, the gauging of the ball, and the resulting reduction of windage. It should be remarked, that the wood before charring has its bark taken off; and for this reason it is best felled in the Summer season, when the sap is up, and will admit of the bark being more easily and cleanly removed. One reason for taking off the bark is, that powder, into which the burned bark enters, is full of sparks, which is, of course, both injurious and dangerous.

The wood made use of is commonly elder, willow, or black-dog wood, and these are said to be very superior for the purpose in the old way of charring, although there are some differences in opinion on this point; but it is generally admitted, that in distilling in cylinders as above described, the particular nature of the wood is by no means important.

Indigo Works.

(601.) Although the preparation of indigo can have no claim to be considered as a British process, yet as it is so important to the art of dyeing, printing, &c. in this Country, and is principally derived from our foreign dependencies, and, moreover, the operation itself being very interesting, we do not hesitate to include indigo works amongst the general list of those which relate to the preparation of various substances of a similar class employed in the Arts and Manufactures of Great Britain.

Indigo, the most important of the vegetable colours used in dyeing, unlike logwood, madder, and most other colours, is extracted from the tree or shrub which contains it, before it arrives in this Country. It is usually imported into Great Britain from the West Indies and America; it is also made in the East Indies, where its cultivation has latterly been much encouraged.

Indigo, or its basis, is contained in the *Isatis tinctoria* which grows in temperate climates, and in some leguminous plants of warmer latitudes, particularly various species of the *Indigofera*. The plants from which our indigo is usually produced are, 1. *Indigofera anil*, a large American plant, which affords indigo of good quality. 2. *Indigofera tinctoria*, a Chinese and Indian plant, which has been carried to America; this is less hardy but more productive than the preceding. 3. *Indigofera disperma*, which affords the Guatemala indigo; its produce is uncommonly fine, but not abundant. 4. *Indigofera argentia*, which produces the indigo bastard of the French; and, 5. *Nerium tinctoria*, from which the East Indian indigo is now produced.

(602.) *History of indigo*.—Considerable uncertainty seems to exist about the early history of indigo, which probably arises from the circumstance of all Indian productions having been brought at that time over land, or

Manufac-
tures.

partly by the Persian Gulf and partly by land to Babylon, or through Arabia and up the Red Sea to Egypt, from which it was transported to Europe. Considering this long carriage, and that the article was not obtained in a direct manner, it is not surprising that our knowledge with respect to its actual Country and the manner of preparing it should be very uncertain and imperfect.

It is the opinion of most authors that the substance termed by Dioscorides *indicon*, and by Pliny and Vitruvius *indicum*, is the same as our present indigo. It is described as a blue pigment brought from India, and used both in painting and dyeing. When pounded it gave a black powder, and when diluted in water produced an agreeable mixture of blue and purple.

Indigo seems to have been mentioned by the Arabian Physicians, and Muratori gives a Treaty written in Latin, of the year 1193, between the citizens of Bologna and Ferrara, which contains a list of those articles subject to pay duty, among which occurs *indicum*. In the XIIIth Century the celebrated Marco Polo, who spent twenty-six years in travelling through Asia, and even some parts of China, relates, that he saw indigo, which the dyers used, made in the Kingdom of Coulan or Coilum, and he describes the process of preparing it.

Much curious information with respect to the trade in this article in the middle of the XIVth Century is contained in the valuable Works of Francesco Balducci Pegolotti. We there find the names of different kinds made use of at that time; such as *Indaco di Buldacca*, detto *buccaddeo*, in all probability from Bagdad, a city which, in many old books of travels, is called Baldach, or Buldac, also *Indaco del Golfo*, *Indaco di Cipri*, &c. Indigo, at that time, was imported in hides (*cuojo*) or in leathern bags (*otre*.) Nicolo Conti, who travelled through India before the year 1444, mentions *endego* among the merchandise of Camboia.

The first Portuguese ship returned from the East Indies in the year 1499, and was soon followed by others laden with the most valuable merchandise of the East. Beckmann, in his *History of Inventions*, states, that he was never able to obtain the invoice of the cargoes of these vessels, but has no doubt that indigo was among the first articles.

Barbosa, a Portuguese who collected in 1516 valuable information with respect to Geography and Trade, who afterwards accompanied Magellan in his voyage round the world, and perished with him at the Island of Zebu, has given a price current of the merchandise at Calicut, in which the value of good indigo at that time is stated. Corsali, also, in his letters written from India in the same year, mentions indigo among the wares of Camboia.

Niska, who wrote in 1630, says indigo had been introduced into Germany only thirty years; and an order of the Emperor Ferdinand III., dated 1654, says, that it had been imported into Germany from Holland some years before that period. That the importation at this time was very great is proved by the cargoes of the ships which arrived in Holland from the East Indies in 1631. The first had 13,539 pounds of Sirches indigo; the second 82,734 pounds of Guzerat indigo; the third 66,986 pounds of the same; the fourth 50,795 pounds of Bejana indigo; the fifth 32,251 pounds of Chirches indigo; the sixth 59,698 pounds of Bejana indigo; and the seventh 27,532 pounds of Chirches. These seven vessels, therefore, brought to Europe 333,545 pounds of

indigo, which at a low valuation were worth 500,000 dollars. Mechanical Processes.

The profit attending this trade induced people soon after the discovery of America to manufacture indigo in that Country; and they were the more encouraged to do so by observing that the native Americans, before they became known to the Christians, tinged their bodies and faces of a blue-violet colour, by means of indigenous plants, which resembled the indigo plant of Asia.

Whether the two plants are of the same genus, and whether the American is different from that used in other quarters of the Globe, does not seem to have been with certainty determined. It is, however, proved, that the assertion of Raynal and others, of this plant being first conveyed to the New World from Asia by Europeans, is entirely erroneous. It is mentioned by Francis Colon, in the life of his father, among the valuable productions of the Island of Hispaniola or St. Domingo. Francis Hernâdes reckons it among the natural plants of Mexico, and says that the Americans used it for dyeing their hair black. He adds that they made it from a pigment which they named Mohuilli and Tleuohuilli, the same as the Latins named *cæruleum*, and he describes also the method of preparing it. This is confirmed by Clavigero, who published an account of Mexico.

This plant must therefore be reckoned among the few which are indigenous in three quarters of the Globe. It is, however, highly probable that the Europeans in the course of time introduced a better species or variety in America, where several kinds are cultivated at present.

The indigo was now brought from both the Indies to Europe, and was found so superior in the richness of its dye, the facility with which it could be used, and other advantages attending it, that it suddenly banished from all dye-houses the European woad, which was cultivated in particular in Thuringia, in Germany, in Languedoc, in France, and in the neighbourhood of Rieti in the dominions of the Church. At first, only a small quantity of indigo was added to the woad, by which the latter was much improved; more was afterwards gradually used, and at last the quantity became so large, that the small admixture of woad served only to revive the fermentation of the indigo. Germany thus lost a production by which farmers, merchants, carriers, and others acquired great riches. In consequence of the sale of woad being so much injured, a prohibition was issued against the use of indigo by Saxony, in the year 1650. In the year 1652, Duke Ernest the Pious caused a proposal to be made to the Diet by his envoy, Dr. Hænnen, that indigo should be entirely banished from the Empire, and that an exclusive privilege should be granted to those who dyed with woad. This was followed by an Imperial prohibition of indigo on the 21st of April, 1654, which was enforced with the greatest severity in his dominions. What was done in Germany with regard to Thuringia was done in France with regard to Languedoc. In consequence of an urgent representation of the States of that Province, the use of indigo was forbidden in 1598, and this prohibition was afterwards repeated several times. But in the well-known Edict of 1669, in which Colbert separated the fine from the common dyers, it was stated that indigo should be used without woad; and in 1737 dyers were left at liberty to use indigo alone, or to employ a mixture of indigo and woad.

Manufac-
tures.

In England, where, at that time, it appears that woad was not cultivated, the first mention of indigo in the laws occurs in the year 1581, under the reign of Elizabeth; not, however, on account of a blue but a black dye. No woollen cloths were to be dyed black with the nutgall, madder, and other materials, till they had received the first ground, or been rendered blue by woad, or woad and indigo together; the consequence of which law was an increase in the consumption of indigo; and from that time the use of indigo has gradually increased in this Country, and now forms a very important article of commerce, producing a revenue of upwards of £30,000 per annum.

Culture of
indigo.

(603.) *Culture of indigo.*—In the cultivation of this plant, one of the most important points to be attended to is, to have the ground thoroughly drained and cleared from weeds. The soil should be fine and rich, and the climate warm; and the season of sowing should be rainy, as the earth must either already have imbibed water, or rain must speedily follow the sowing, otherwise the seed becomes heated and rots, and all the labour spent upon it is of course lost. The ground being prepared, a number of slaves ranged in a line march across making little trenches of the width of their hoes, and two or three inches deep, and about a foot distant from one another every way; then returning, they drop some seeds in each trench, and afterwards cover them with the earth taken out.

During the process of vegetation the ground must be carefully weeded, in order to prevent any mixture of herbs, which would injure the indigo in its manufacture. In moist weather the plant comes up in two or three days, and in about two or three months after it is fit for cutting. If suffered to run until it runs into flower, the leaves become too dry and hard, and the indigo obtained from them proves less in quantity and less beautiful: the due point of maturity is known by the leaves beginning to grow less supple or more brittle. In rainy seasons, the cutting may be repeated every six weeks: cutting in dry weather kills the plant; but if that is avoided, one plant will continue to afford fresh crops for two years.

The manner in which it is commonly prepared is as follows: a large quantity of the herb is put into a vat or cistern of strong mason-work, with so much water as is sufficient to cover it, and some wood is laid above to prevent it rising up. The matter begins to ferment sooner or later, according to the warmth of the weather and the maturity of the plant, sometimes in six or eight hours, and sometimes in not less than twenty. The liquor then grows hot, throws up a plentiful froth, thickens by degrees, and acquires a blue colour, inclining to violet, and in proportion as the heat increases, azote is disengaged, the vegetable is decomposed, and the mixture absorbs oxygen; the fermenting fluid passes from a green to a violet tinge, and this by degrees changes to a blue colour. The great art of the manufacturer is to check the fermentation at a proper degree; for if it is checked too soon, the plant remains impregnated with much essential salt, which diminishes the quantity of indigo; and if allowed to remain too long, the tender extremities of the plant undergo a putrefaction which destroys the beauty of the colour. Some years ago, a method of invariably ascertaining the correct fermentation of the indigo was published at St. Domingo, which consisted in writing on white paper with the matter to be examined, and if the ink be of a very

high colour it is a proof that the fermentation has not arrived at its true point. The experiment is repeated every quarter of an hour, until it is perceived that the liquid has lost its colour, which is said to be a very correct method of ascertaining the proper degree of fermentation. Others pour a quantity of the liquid into a silver cup, which they shake until the grains are deposited, and judge by the quality of them the proper state of fermentation. When the feculent particles begin to be precipitated to the bottom of the cup, it is then judged that the herbs have attained the true degree of maceration to obtain indigo. Five or six minutes after the liquid has been put into the cup, it is perceived to form round its edges a cordon of feculæ or sediment, at first of a green colour and then blue. When the maceration is not at the requisite point, the cordon or girdle detaches itself with difficulty from the sides of the cup, but finally precipitates, and the water above it becomes limpid, although of a yellowish hue. When these signs are perceived, they infallibly indicate the success of the first operation.

The liquid impregnated with the tincture is then let off by cocks in the bottom of the vessel into another vat placed for that purpose, without disturbing the herb.

In the second vat the liquid is strongly and incessantly beaten and agitated with a kind of bucket fixed to a pole, until the colouring matter is united into a body. A good deal of nicety is required in this operation also, for if the beating ceases too soon, a part of the colouring matter remains dissolved in the liquid; and, if continued too long, a part of that which had separated is dissolved afresh. The exact time for discontinuing the process is determined by taking up some of the liquor occasionally in a little cup, and observing whether the blue fecula is disposed to separate and subside.

The whole being now suffered to rest until the blue matter has settled, the clear water is let off by cocks at different heights in the sides of the vat, and the blue part discharged into another vat by the cock at the bottom. Here it is suffered to settle for some time longer, then further drained in cloth bags or sacks, and exposed in shallow, wooden boxes to the air, without admitting the sun, and carefully keeping it from the rain till thoroughly dry.

Before it is quite dry, it is cut into small pieces of an inch square, which may be detached readily from the box when it is quite dry. Yet, however well dried and drained the indigo may be, it always experiences in the first month of its fabrication a considerable diminution of quantity. It is packed for commerce either in barrels or in sacks of coarse linen, covered with ox-hides, so perfectly sewed together as entirely to exclude the air. These packets are called "ceroons;" they are much preferable to barrels, as they are more solid and more conveniently transported from one place to another.

Indigo is commonly divided, from the colour it exhibits when broken, into three kinds, viz. copper-coloured, purple, and blue. These different appearances probably depend upon the different methods of preparing the indigo used by different manufacturers, upon the age of the plant, which greatly influences the appearance of the indigo, or upon the time at which the plant is gathered. The superiority of some of the indigoes of the East Indies over those of America is said to proceed from the leaves of the plant being alone employed and the twig thrown away. Some heat the water in the steeping

Mechanical
Processes.

Manufac-
tures.

Dr. Rox-
burgh's
description
of the tree.

vat with a view to increase the quantity extracted, but this is considered to debase the quality of the indigo, by the substance of the leaves and the bark becoming blended in water with the colouring matter.

(604.) We add the following account of the tree, and the method of preparing the Nerium indigo, extracted from a communication from Dr. William Roxburgh of Calcutta to the Society of Arts.

The tree from which this indigo is obtained is elegant in form and middle-sized, perfectly agreeing in character with the genus *Nerium* of the Linnæan sexual system. The trunk is short and erect, and in large trees reaches the size of one foot six inches or two feet in diameter. Its height when full grown varies from twenty to thirty feet. The wood is white, close-grained, and very beautiful, approaching the colour and appearance of ivory. The leaves are numerous, of a pale green colour, pointed, and of an oblong shape; when full grown from six to ten inches long, and from three to four broad.

This, with a variety of it with leaves considerably longer and narrower, and somewhat downy, which also yields indigo, but of an inferior quality and less in proportion, are natives of the hills and lower regions of the mountains directly North from Coringa, in the Rajah-Mundry-Circar, and delight most in the South and sunny side of these hills and mountains. It also grows in similar places in other parts of the Circars and in the Carnatic, being an extent of country of more than one thousand miles in length.

To cause the trees to yield a large supply of the best leaves for making indigo, it is necessary to keep them low as found in the vicinity of the habitations of the natives, by cropping off the branches, which causes many shoots to issue from the cut stumps. These in one year acquire various heights of from one to ten feet, according to the nature of the soil, and yield a great quantity of leaves.

The leaves begin to be fit for making indigo in the month of April, but in May and June, which is the hottest time of the year, are found to yield a better colour than in any other month. About the end of August, the growth of the plant begins to draw to a close for the season: the leaves acquiring a yellowish-rusty hue soon fall off, without being succeeded by others, or in a trifling degree until next season; so that with the plants in a wild state, which is the state alluded to in these observations, the length of the season for making indigo can only be reckoned at from four, or at most five months of the year.

Dr. Roxburgh tried the leaves of some plants raised from seed in his garden, but found they did not yield colour until several years old, and then but in a trifling degree, and of a quality inferior to that which the wild plants afford in their natural soil; and he remarks that it is the same with the young plantations in Bengal. If the leaves are culled and only the best chosen, the indigo is considerably more beautiful than when taken promiscuously with the extremities of the branches, when some (the lowermost on the shoots) will be rather too old, some at the extremity too young, and those of the middle part only of a proper age. He could never extract any thing like blue indigo from the tender shoots of this plant when deprived of their leaves, which is not the case with the twigs of the common indigo plant, which when totally deprived of its leaves will yield a tolerably good indigo, although inferior to that produced by the same process from the leaves alone.

The author made several experiments, because he considered it of importance to determine this point, that care might be taken to prevent the labourers from plucking the twigs, which they will always do if not strictly watched, because they can fill a basket or measure much sooner if permitted to bring them along with the leaves. Manufacturers of the *Nerium* indigo require to attend to this, otherwise they will gather the twigs with the leaves upon them, which will both diminish the produce of indigo and debase its quality.

The leaves, when collected in sufficient quantity, are put into the copper, so as to fill the vessel without being pressed down, and then the vessels are filled with cold water to within three or four inches of the top. This space is required to be left, because the bulk enlarges by heat as much as the common indigo vat does by fermentation. Dr. Roxburgh tried different kinds of water, viz. rain water, soft water from wells and from a river, and various kinds of hard water, and found the hard water to give the best indigo, and in the largest proportion.

The fire is then lighted, which must be maintained rather briskly until the liquor acquires a deep green colour when viewed in the vessel; but if taken up and poured from one vessel to another, a pale but bright greenish-yellow; the leaves will then begin to assume a yellowish colour, and the heat of the liquor will be about 150 or 160 degrees of Fahrenheit's scale. The leaves must be constantly agitated and turned upside down to produce as nearly as possible an equal degree of scalding, if not, those at the bottom would be much overdone before those at the surface were ready. The motion answers another purpose; it serves to expel the fixed air which greatly forwards the operation. The fire must be withdrawn or suffered to die away some little time before the liquor has acquired the above-mentioned appearance; and it is necessary to have all the different vessels that are to be let into the same agitation-vat ready at the same time. When they are ready, the whole is drawn off at once. A contrivance must be had recourse to to let the liquor pass through a hair-cloth, (a coarse *comly*, such as the poorer classes of the natives wear in cold weather, answers perfectly well,) to prevent any of the leaves, &c. from getting into the agitation-vat. As soon as the whole is run off, it must be, while hot, agitated in the common way for some minutes; from five to twenty will generally be found sufficient to produce the necessary degree of granulation. About from one-seventieth to one-hundredth part of strong pure lime water is then let in from the lime-water cistern, the liquor being still hot, which requires only to be sufficiently mixed with the liquor to produce quickly a very large grain which soon precipitates. The supernatant liquor is then let off, and the rest of the process is the same as is employed in making the common fermented indigo.

If the process has been properly conducted, the supernatant liquor will run off of a clear Madeira-wine colour, which is a sign that it retains none of the indigo. The produce of the indigo when dry will average about one pound for every two hundred and fifty pounds of green leaves, but varies according to the season and state of the weather when gathered. Dr. Roxburgh found that by the end of August or September they would not yield much more than one-half or two-thirds of the quantity which they give in May or June, and even that is diminished if the weather be wet, or if the leaves are committed to the fire immediately after they have been gathered.

Mechanical
Processes.

Manufac-
tures.

The operation is performed with ease twice a day ; it may be performed three times. The scalding to the degree already mentioned requiring only about three hours and the agitation and precipitation not more ; so that by the time the scalding is completed, the fecula of the preceding operation is ready to be removed from the large agitation-vat into the small cistern, where it is to remain until the fecula has precipitated into a still smaller bulk. The supernatant liquor is then let off by scuppers, and the fecula is put into bags to drain.

M. de Cossigny, in his *Treatise on the Cultivation and Manufacture of Indigo*, observes, that it is much improved if the moist fecula is washed with warm water, in which a small quantity of acid of vitriol has been mixed ; this Dr. Roxburgh also considers to improve the Nerium indigo. A small quantity will suffice. The use of the acid seems to be to dissolve any remains of the calcareous precipitant, or other extraneous matter that may unavoidably be mixed with the fecula ; all of which ought to be further washed off by several subsequent washings with pure water, which is the better for being hot.

Description
of an indi-
go work.
Pl. xlvii.

(605.) A plan, section, and perspective view of the apparatus used in the Nerium indigo manufacture is shown in plate xlvii. where fig. 1 is a perspective view ; fig. 2, a plan taken at the iron bars or grating which support the coppers ; fig. 3, 4 a longitudinal and transverse section to exhibit the internal structure of the works. The same letters refer to all the figures.

A is a cistern for holding water in readiness to fill the coppers ; it is fifteen feet square and three feet deep ; *a* is the channel for conducting the water from the cistern into the coppers, which is about two inches above the bottom to allow the impurities to settle ; *b* is a channel by which the impure parts of the liquor are occasionally drawn off for the cistern to be cleaned.

To raise the water to fill the cistern is an object of much consequence ; in several places amongst the hills where the Nerium grows there are little rills of water running upon such a descent as to render it only necessary to construct the works on some low adjacent spot, that the water may be conducted with little trouble into the cistern. When no such supply of water can be had, pecotahs, or a chain pump made of four boards, as described in our hydraulic engines, article 340, *et seq.*, may be used, or if the water is very low, it may be done by the funnel-like leather bucket shown in the figure, which is wrought by a pair of buffaloes or bullocks. To the mouth of the tube or pipe of this leather funnel bucket, (see fig. 1,) is fastened a cord *a*, which leads over a roller placed at least the length of the body of the bucket below the wheel V. The bucket is raised by two ropes, one of which raises the body of the bucket, and the other the funnel end of the same. The cord *a* which supports the funnel end of the bucket is of such a length as to keep the mouth of the funnel rather above the square mouth until it reaches the roller, when the end passes into the trough while the body of the bucket continues to ascend until the bottom is above the level of the trough, by which time the whole of the water will have made its escape. This method of raising a large quantity of water from a great depth is in common use over many parts of Hindostan, where the wells are too deep for the use of the pecotah or lever. It is of great advantage to have the water in readiness in this manner, for it not only forwards the work much, but also gives time for any impurities to settle at the

bottom. In the perspective view the cistern A is omitted to show the other parts of the work on a larger scale.

B are the coppers or scalding vessels resting on the grate *c*, which is supported by the walls and by the pillar *d* ; they are made to communicate with each other by the openings *e* ; *f* is the top of the walls which surround the vessels ; they are made two or three inches lower than the edge of the coppers to prevent dust getting in, and sufficiently broad for the workman to walk about upon to attend the work ; *n* are the fire-places. C, the agitation-vat or beater, twenty feet square and three deep, one foot of which may be called the border, being made thinner ; it prevents the dust and dirt getting in from the feet of the workmen while walking about to agitate the liquor, &c. ; *h* are two scuppers for letting off the clear supernatant liquor from the fecula ; *i* another by which the fecula is drawn off ; D the lime-water cistern, which may be made with a border and lid to exclude the air or arched ; it has an opening at the top to put lime and water in at, and for a boy to go in to clean it ; the closer this can be shut, the better the lime water will be ; *k* the scupper for letting the lime water into the agitation vat.

E the small fecula cistern for the fecula to further settle in ; *l* the scuppers to let off the supernatant liquor, over which the bags are hung until the liquor drops clear of them.

The transverse section, fig. 4, is upon a larger scale than the former. It is made through the middle of one of the coppers F, and through the middle of one of the arched openings *m* which serve to feed the fire. This shows the channel G for carrying the scalded liquor from the boilers to the agitation-vat C, fig. 2, 4 ; it is supported by four beams extended between the abutments ; *n* is one of the scuppers, by which the liquor runs from the coppers to the channel G ; *d d* are pillars which support the square bars of iron of the grate ; *q* the opening which communicates with the next copper. To prevent any leakage at these communications, and to be able to separate the vessels, Dr. Roxburgh suggested the following contrivance ; it is represented in fig. 4. Holes are made in the sides of the two contiguous coppers corresponding with the four screws. A thick square piece of welted hide, with a square hole corresponding with the holes in the sides of the vessels, is slipped in between them, and the two plates of iron shown in fig. 5 are placed one in each copper, and screwed very tight together.

Fig. 6 are two beaters, each being a square-headed churn-staff, which answers exceedingly well to turn the leaves while scalding, and afterwards to agitate the liquor with ; four of them are found sufficient for an ordinary vat. If workmen for joining the sheathing can be had where works are to be erected, Dr. Roxburgh considers it would be a saving of copper, and otherwise more convenient, to have only one vessel : the length may be made as much as may be necessary for the quantity of leaves that may grow in the vicinity of the place. If constructed in this manner, there will be no need of the channel G in front of the vessels : one large scupper from the end of the vessel next the agitation-vat is all that is thus necessary ; the other parts may remain as above mentioned.

Dr. Roxburgh afterwards joined the above-mentioned six vessels into one, by cutting out the divisions and joining them upon the grate : with the copper so got out from the sides, he lengthened the now single vessel

Mechanica
Processes.

Manufac-
tures.

to more than forty feet. This required ten additional fire-places, as a fire was necessary to every five feet of length when the vessel is ten feet broad, which is a surface of fifty square feet for each fire to act upon. *Transactions of the Society of Arts*, vol. xxviii.

Litharge.

(606.) This is an oxide of lead, made by the simple action of heat and air on the metal; it is produced in the process of extracting silver from lead, and has been already explained under the latter head.

Minium or Red Lead Works.

Red lead.

(607.) The process of making red lead in Derbyshire is described by Dr. Watson in his *Chemical Essays*, vol. iii. as follows. The furnace is much like a baker's oven with a low vaulted roof, and on each side of the furnace are two party walls rising from the floor of the furnace, but not reaching to the roof. In the interval between these walls and the sides of the furnace the coal is burned, and the flame, drawn over the top of the party wall and striking against the roof, is thence reflected down upon the surface of a quantity of lead which is laid on the floor of the furnace. The metal soon melts, and instantly becomes covered with a pellicle which is successively raked off till the whole is changed into a greenish-yellow powder. This is taken out, ground in a mill, and washed, to separate the portion of lead that still remains in the metallic state, by which it becomes a uniform yellow colour, and is then thrown back into the furnace and constantly stirred, so that every part may be equally exposed to the action of the flame, and after about forty-eight hours of calcination it is converted into red lead.

Some practical nicety is required in the management of the fire, which, if too slack, gives only a yellow or orange-coloured powder, and, if too fierce, makes the minium dusky, and destroys that brilliant gloss for which it is so much admired. There are besides other minuter circumstances of management, and probably kept secret as much as possible. Jar mentions in particular that of cooling the minium very gradually, and closing all the openings of the furnace, otherwise, he says, the beauty of the colour is much impaired.

Ceruse or White Lead Works.

White lead.

(608.) This is a carbonate of lead prepared in the first part of the process of making the acetate of lead. First, lead is melted and cast in a case or mould, so as to form a sheet of about 2 feet 5 inches broad, and from one-sixteenth to one fourth of an inch thick. The lead in this instance is cast at once of the proper form, and not mechanically flattened like sheet lead, that its texture may be more open, and more easily penetrated by the acid vapour. These plates are then rolled up into a loose coil, and each is placed perpendicularly in an earthen pot, like a common garden pot, holding from two to six pints each, but with a ledge on the inside about half way down, on which the coil of lead rests, so that it may not touch the bottom. Each pot is filled with vinegar of any kind, just so high as not to wet the bottom of the lead, and the whole is also covered with a plate of lead fitted very close. The pots are then ranged under a building, so as to shelter them from the weather, and buried pretty deep in fresh stable litter or tanner's bark, layer upon layer,

according to the number of pots. The heat of the dung soon fills the upper part of the pots with the vapour of the vinegar below, and the lead kept constantly in contact with the acid vapour, but not immersed in the liquor, presently begins to corrode and oxidate at the surface. The pots remain under the litter for about two months, at the end of which time they are taken out and the coils of lead are found deeply corroded, and the surface converted into a whitish, scaly, brittle oxide. This is separated by passing the plates between rollers, which causes it to peel off, leaving the lead beneath in the metallic state. This oxide is then mixed with a little water, and passed between a pair of mill-stones; then the finer parts are separated from the coarser by successive washings, the former being longer suspended in water than the latter, till the whole of the finer oxide is obtained. This is then dried either in the air or in large airy rooms, warmed by a small stove, and is then perfect ceruse or white lead fit for use. Of late years the scales of oxide, instead of being separated from the coils by dry laminating, which raised a dust of lead highly injurious to the health of the people about them, are detached by spreading the coils upon a perforated wooden floor covered with water, and drawing them to and fro by rakes, which detaches the oxide, and causes it to sink through the water and the holes of the floor to the bottom of the vessel below. *Aikin's Dictionary*.

Acetate or Sugar of Lead Works.

(609.) Sugar of lead is used very largely in various manufactories of this Kingdom, particularly in calico printing, and the works for preparing it, although very simple, are confined to very few places. Most of the sugar of lead used in this Country is imported from Holland. This salt is made very nearly in the manner of ceruse; that is, lead sheets are put into pots with vinegar, and digested a sufficient time, but here the vinegar is distilled, and the plates, instead of being entirely out of the liquor, are half immersed in it. This being done, the upper half is soon covered with an efflorescence of ceruse, after which it is immersed in vinegar, and the part which was before immersed is now brought up to be converted into ceruse as before, when the plate is again turned, and the newly oxidated surface in its turn immersed in the liquor. The plates are thus turned about two or three times a day, and the vinegar in saturating itself with the ceruse becomes milky, and soon sufficiently impregnated to be boiled down to the crystallizing point, which is done in tinned vessels to about a third of the original quantity. This is then strained, and, on cooling, deposits the acetate in small long needles in irregular whitish crystals. The mother-liquor is again evaporated for a fresh crop of crystals, but these are browner and somewhat deliquescent. Acetate of lead may also be made directly by dissolving ceruse or litharge in vinegar, and probably the natural carbonate will answer the same purpose. Some technical nicety appears to be required in making the salt crystallize in the large way.

Potash.

(610.) This is an article of great application in various branches of the Arts and Manufactures of this Country, and is principally obtained from the combustion of vegetables, although it exists also in a mineral state. If the woody or annual stems of vegetables, which have grown in soils unimpregnated with common salt, after being

Mechanical
Processes.

Sugar of
lead.

Potash.

Manufac-
tures.

sufficiently dried, are set on fire; the watery, resinous, oily, acid, and carbonaceous portions are volatilized and dissipated in a state of more or less complete decomposition, and there remains behind a reddish or whitish powder, called ash or ashes, consisting principally of earthy or metallic ingredients of the vegetable, together with a variable proportion of subcarbonate of potash. By lixiviation with hot or cold water the alkaline part is dissolved out; and this solution, when boiled down to dryness, leaves behind a dark brown saline mass, consisting of the carbonated potash, coloured by a small portion of vegetable, inflammable matter, and in this state it is known in the English market by the name of potash. Calcination, at a moderate red heat, completely burns off the colouring principle, and the salt becomes of a spongy texture, with a fine bluish-white tinge, and is then called pearl ash.

Ash balls
of England
and Ireland.

A large proportion of the potash used in England is imported from foreign Countries which abound largely in woods, as Germany, Russia, and America; but a very rude preparation of the same is produced both in England and Ireland, principally from the burning of heath and fern. In neither, however, can it be considered as a general article of commerce, although considerable quantities are annually made by the peasantry of both Countries, and disposed of amongst the neighbouring farmers and bleachers under the name of *ash balls* or *weed ash*.

In Ireland, the vegetable from which this impure alkali is produced is the common fern or brake. Many rough and heathy districts are entirely covered with this plant, which, when it has attained its growth, about the middle of July, is cut down, and, after being half-dried in the open air, is gathered into smaller heaps and kindled. The combustion proceeds slowly, being accompanied by a smothering smoke and little or no flame, till the whole is reduced to a reddish-grey ash; this being carefully collected is sprinkled with a little water, and then moulded by hand into balls from three to four inches in diameter, which, when they have acquired a certain hardness and solidity by drying in the sun, are ready for sale. In Ireland, thistles, docks, and weeds of all kinds are mixed with the fern, and the ashes are disposed of in their loose pulverulent state, without any further preparation.

The general potash of commerce, or black potash, is, as we have stated, chiefly of foreign manufacture, which can be carried on to advantage only in Countries which are not only thickly covered with wood, but where, for want of roads, or other means, the wood itself cannot be removed to a profitable market, or where the object of clearing the country of wood is of more importance than the wood itself. Different processes are adopted in different Countries, but as the subject is not connected with our present object, *viz.*, an account of the principal Manufactures of Great Britain, it will not be necessary to describe them.

Salt Works.

Common
salt defined.

(611.) Salt, or common salt, is a substance of necessity so immediate to the health and conveniences of life, and of application so extensive in agriculture and in the Arts, that it is perhaps in more general use than any other natural or artificial production whatever. For many years, it was considered by Chemists to be a compound of muriatic acid and soda, the latter having been

supposed a simple body; but Sir H. Davy having succeeded in decomposing soda, common salt is now considered as the chlorate of sodium, the latter being the metallic base of soda.

Mechanical
Processes.

There are three great repositories of salt found in nature; *viz.* sea water, which is impregnated with the elements of this substance; brine pits and brine springs, which are more largely imbued with them; and salt rocks, in which the salt is combined more or less with earthy matter. It is stated above, that common salt is a compound of muriatic acid and soda, or of chlorine and sodium, but this implies its most perfect form; generally, our domestic salt contains, besides the basis of the salt, other foreign matters and impurities, and is indeed distinguished under different heads, according to the sources and processes from which it is derived, or the nature of the foreign matter with which it is combined.

Natural
depositories
of salt.

1. *Bay salt* is a name given to salt prepared by evaporation. This is of two kinds: the first drawn from sea water the second from the water of salt springs or lakes.

Different
sorts of
salt.

2. Marine salt, extracted from sea water by boiling.

3. Brine salt, also prepared by boiling, but from the natural brine of ponds, fountains, or streams.

4. White salt, obtained by first strengthening the sea water or natural brine by evaporation, and then completing the rest of the process artificially.

5. Refined rock salt, boiled from a solution of fossil salt in salt or fresh water.

The climate of this Country will not admit of the formation of salt wholly from natural evaporation; on some parts of our Southern coast it is first concentrated by atmospheric evaporation, and the process completed by artificial heat, but in our Northern Counties, and in Scotland, the whole process is performed by artificial means. The English salt rocks and brine springs are almost entirely confined to Cheshire, of which we shall give a particular description below. At present we shall confine ourselves to the means employed to obtain salt from sea water.

(612.) *Processes for obtaining salt from sea water.*— There are several ways of obtaining salt from sea water; in warm climates, this is done altogether by the heat of the atmosphere; and this forms the large-grained, strong, dry salt, called *bay salt*, which is preferred to any other for curing provisions that are intended to keep for a length of time. Bay salt is made in great perfection in Spain and Portugal, by the Biscayans; on the Mediterranean shores of France, and in the Bahama Islands in the West Indies. The process is simple, and requires but little apparatus of any kind. The first requisite is a sea marsh, or shallow artificial pond, near enough to the sea to be filled at high water; a level shore must therefore be chosen, and the soil must be clayey to retain the water. The bottom of the pond is then laid out perfectly even, and beaten hard and smooth, and a channel with flood-gates is cut to the sea, so that the salt pool may consist of a large reservoir communicating directly with the sea at one end, and at the other with a number of smaller pits or beds on which the salt is made. The water is first evaporated by the sun's heat in the reservoir, and then conveyed to the salt beds, which are only a few inches deep, and in which the evaporation is completed also by the sun and wind, and the salt separated, first in the form of a white crust, which is afterwards broken from time to time to expose a fresh surface to the air. The concentrated brine yields salt about twice, and sometimes

Process of
obtaining
salt from
sea water :
1st by
natural
evaporation.

Manufac-
tures.

2d, partial
evapora-
tion.

3d method.

4th method.

thrice a week in the summer. The first saline crust which is formed is small-grained, the latter large. Bay salt has generally a little tinge of colour, green or brown, according to the soil on which it is formed. It is only made in the summer months.

Another way of making salt from sea water, which is practised much on the French and other coasts of temperate climates, is partly by the atmospherical evaporation, and partly by boiling, for the summers are not hot enough in such climates to make salt by mere exposure of brine to the air. The general mode of proceeding is that already mentioned; that is, the sea water is exposed during the summer in shallow artificial pools, where it becomes highly concentrated, and this is afterwards boiled down in iron pans in the usual mode. This way is adopted in some parts of England, particularly at Lymington. The mother-water which remains after most of the salt has been extracted, contains much muriate of magnesia, and this is advantageously converted into the *sulphate of magnesia*.

There is still another method of extracting the salt from sea water, which is by collecting the sand that has been repeatedly moistened by the sea water and dried, and lixiviating it in the reservoirs, where it forms a very strong brine, which is then boiled down as usual. This method is much practised on the Western coast of France, particularly in Lower Normandy, and at the Isles of Oleron and Rhé.

The spot being chosen, (which should be on a level shore with a clean sand,) the necessary buildings are erected, namely, evaporating pans, store-houses, covered sheds, &c., and an area of three or four acres is selected a little below the level of the spring tides and above the neap. The surface is carefully levelled by the plough, and rolled smooth and hard; it is then filled to the height of several inches with sand taken from the edge of the sea at low water, and the sand is also drenched with sea water as the tide flows in. It then lies exposed to the sun and wind, which soon dissipate the superfluous water, and the surface of the sand appears covered with a white efflorescence. This is turned over frequently with a kind of shovel, changing the surface several times a day till the whole is thoroughly dry. This saline sand is then carried to the sheds, and the process is repeated with fresh sand till a large quantity is collected, which generally employs the whole summer. To make the salt, the dry sand is taken out of the sheds and thrown into small round pits about two and a half feet in diameter, and twelve inches deep, the bottoms of which are lined with hard-rammed clay mixed with chopped straw, to prevent the water from oozing through. The sand is then covered with sea water, or with the weaker lie of former operations, and after standing some hours is drawn off into reservoirs or barrels, whence the evaporating pans are immediately supplied. The sand is lixiviated a second time, and this lie is reserved for a fresh portion of sand. The boilers are of lead, about three and a half feet square, and four or six inches deep. They are heated with wood of any kind, or sometimes with reeds, and a boiler of this kind is worked off in from two to three hours. The salt is raked out as it is formed, and drained in hollow cones, as in other places. Three pans of the above dimension yield together about five pounds of salt.

The salt procured in this way is white and small-grained, but it is very apt to be damp, and is a weak-bodied salt little fit for preserving animal food for any length of time. In a few Northern Countries, some

advantages is made of the effect of cold to concentrate brine, by freezing at first only the more watery part, of course leaving the unfrozen part proportionally richer in salt. The winters of this Country are not cold enough in general for this purpose, but it is occasionally used on the Baltic coasts. The cold, however, must not be too intense, otherwise the brine itself freezes. Frozen salt water is not in hard solid masses like fresh water, but is soft and crumbly or rotten. The efficacy of this method of concentrating brine is very inconsiderable.

(613.) *Description of the Cheshire salt district.*—We have stated the other repositories of salt to be salt rocks and brine springs, which in England are found only in Cheshire and its immediate neighbourhood. A very interesting account of this salt district has been given by Mr. Holland, in a Memoir published in vol. i. of the first series of the *Transactions of the Geological Society*, from which it appears that the rock salt occurs from 28 to 48 yards beneath the surface of the earth. The first stratum or mine is from 15 to 21 yards in thickness. It very much resembles in appearance brown sugar-candy, is perfectly solid, and so hard as not to be broken but with great difficulty by iron pikes or wedges. Of late, the workmen have been accustomed to blast it with gunpowder, by which means they loosen and remove many tons of it together. Beneath this stratum there is a bed of hard stone, consisting of large veins of flag, intermixed with some rock salt, the whole from 25 to 35 yards in thickness. Under this bed is a second stratum or mine of salt, from five to six yards thick, many parts of it perfectly white and clear as crystal, others browner, but all purer than the upper stratum, yet reckoned not quite so strong. Only these two distinct beds of the fossil salt have been met with at Northwich; but it has been ascertained that the same limitations do not exist throughout the whole of the salt district, three distinct beds, at least, being found in some situations, separated in like manner from each other by intervening strata. The great body of the rock salt, both in the upper and the lower beds, is composed of crystals of muriate of soda, intimately mixed with certain proportions of clay and oxide of iron, containing likewise small proportions of certain earthy salts. At the same time, particularly in the lower strata of the rock, there are found separate crystalline concretions of muriate of soda in a purer state, variously disposed, sometimes occurring distinctly in the cubical form, in other places in masses of larger size and irregularly shaped. Above the whole mass of salt lies a bed of whitish clay, which has been used in the Liverpool earthenware; and in the same situation there is found also a quantity of gypsum.

(614.) Rock salt-pits are sunk at great expense, and are very uncertain in their duration, being frequently destroyed by the brine springs bursting into them, and dissolving the pillars that support the roof; through which the whole work then falls in, leaving vast chasins in the surface of the earth. In forming a pit, a shaft or eye is sunk, similar to that of a coal-pit, but more extensive. When the workmen have penetrated to the salt rock, and made a proper cavity, they leave a sufficient substance of the rock (generally about seven yards in thickness) to form a solid roof; and as they proceed, they hew pillars out of the rock, to sustain the roof. Gunpowder is then employed to separate what is meant to be raised, which is conveyed to the surface in huge craggy lumps, and is drawn up above ground in capa-

Mechanical
Processes.

Cheshire
salt dis-
trict.

Extent of
the Che-
shire salt
district.

Method of
working the
mine.

Manufactures.

cious baskets made for the purpose. When well illuminated, the crystalline surface of the roof, pillars, and sides of a large pit make a glittering and magnificent appearance, which seldom fails to have a very impressive effect on the mind of a stranger. Fresh air is conveyed from the mouth of the pit by means of a tube with a pair of forge bellows fixed to it; and thus a perpetual current is preserved between the outer and inner air. The pits, at the greatest depth, are dry, and of an agreeable temperature.

The largest rock salt-pit in Cheshire is one in the town of Wilton. This has been excavated in a circular form to 108 yards in diameter; its roof is supported by 25 pillars, each three yards wide at the front, four at the back, and six yards in the sides. Each of these pillars contain 294 yards of rock salt, and the whole area of the pit, which is 14 yards hollow, includes 9160 superficial yards, or little less than two acres of land.

The quantity of rock salt delivered annually from the pits in the neighbourhood of Northwich, is from 50,000 to 60,000 tons. Hardly more than one-fourth of this is refined in England, the remainder being exported to various parts of the Continent. The salt is conveyed down the Mersey in vessels of from 50 to 80 tons burthen to Liverpool, where it is reshipped for foreign Countries, or kept to be refined.

Besides the great quantity of salt obtained from the rock, an immense weight is supplied by the brine pits, not less than 45,000 tons being annually manufactured at this town, or in the vicinity. The usual depth of the springs is from 20 to 40 yards; and they are situated on a hill at some distance. The brine stream is raised by a steam engine, and conveyed through very long troughs to the brine pits. The process of extracting the salt is accomplished by heating the liquor in iron pans of from 20 or 30 feet square, and about 14 inches deep. When it boils, a light scum rises to the top, which is taken off, and the liquor reduced to a lower degree of heat; the stream arising is made to evaporate as quickly as possible; and the salt collecting into crystals forms a crust on the surface, which, sinking afterwards to the bottom of the pans, is thence removed once or twice in every twenty-four hours. The salt made in this district is distinguished into stoved or lump salt, common salt, large-grained flaky salt, and fishery salt.

(615.) *Lump or stoved salt.*—In making this salt, the brine is brought to the boiling heat, which in brine fully saturated is 226° Fahrenheit. This temperature is continued during the whole process; and as the evaporation proceeds, small flaky crystals continue to form themselves, and to fall to the bottom of the boiler. At the end of from eight to twelve hours, the greatest part of the water of solution is found to be evaporated; so much only being left as barely to cover the salt and the bottom of the pan. The salt is then removed into conical wicker baskets termed *barrows*, and, after being well drained, is dried in stoves, where it sustains a loss of about one-seventh of its weight.

On the first application of heat to the brine, a quantity of carbonate of lime, and sometimes a little oxide of iron, both of which had been held in solution by an excess of carbonic acid, are separated, and are either removed by skimming, or are allowed to subside to the bottom of the pan along with the salt first formed and with some sulphate of lime, and are afterwards raked out. These two operations are called *clearing* the pan. Some brines scarcely require them at all, and others

only occasionally. The whole of the impurities, however, are not thus removed; for a part subsiding to the bottom, forms a solid incrustation, termed by the workmen *pan-scale*. The portion of this which is lowest acquires so much induration and adhesion to the pan, that it is necessary to remove it once every three or four weeks by heavy blows with a pick-axe. These sediments are formed also in making the other varieties of salt.

Common salt.—The brine for forming this salt is raised to a boiling heat, with the double view of bringing it as quickly as possible to the point of saturation, and of clearing it from its earthy contents. The fires are then slackened, and the evaporation is carried on for twenty-four hours with the brine heated to 160° or 170° Fahrenheit. The salt thus formed is in quadrangular pyramids or *hoppers*, which are close and hard in their texture. The remainder of the process is similar to that of making stoved salt, except that, after being drained, it is carried immediately to the store-house, and not afterwards exposed to heat, an operation confined to the stoved salt.

Large-grained flaky salt is made with an evaporation conducted at the heat of 130 or 140 degrees. The salt thus formed is somewhat harder than common salt, and approaches more nearly to the cubic shape of the crystals of muriate of soda.

Large-grained or fishery salt is prepared from brine heated only to 100° or 110° Fahrenheit. No perceptible agitation, therefore, is produced in the brine, and the slowness of the process, which lasts from seven or eight to ten days, allows the muriate of soda to form in large and nearly cubical crystals.

For ordinary domestic uses, stoved salt is perfectly sufficient. Common salt is adapted to the *striking* and salting of provisions, which are not intended for sea voyages or warm climates. For the latter purposes, the large-grained or fishery salt is peculiarly fitted.

All the pans were formerly, and are still in many works, heated by furnaces beneath them with flues drawing all round, and the fuel is commonly coal; but recently the evaporation is produced by means of steam, as described below. In the former case, each of the pans, which are set securely upon masonry with the furnace below, stands in a covered building, with a pyramidal roof formed of boards sloping downwards, but with a considerable interval between each to keep off the rain, but allowing, at the same time, a free passage for the steam of the boiling brine to pass off.

(616.) *Evaporating by steam.*—Two patents have been granted for evaporating by means of steam, instead of the usual furnace and flues, in one of which a vessel containing the brine is inserted in a steam boiler, or intimately connected with it, the brine vessel being open on its upper part.

In the second by Mr. Furnival, the brine is, as in the other, first pumped into an open vessel at A, fig. 5, plate xlvi., inserted in or fixed upon a close steam boiler B; but the boiler, instead of containing fresh water, contains a still stronger brine than that in the upper vessel. This is brine which has been operated upon in the upper boiler, and let down into the lower one to be finished or evaporated to such a degree that nothing but salt remains. To effect this, a division of sheet iron C is made in the top or upper side of the lower boiler in a diagonal direction, containing an opening d, similar to a dormer window in a leaning roof. This

Mechanical Processes.

Patent apparatus for evaporating.

Pl. xlvi. Fig. 5.

Manufactures.

serves to let out the steam, but will not admit any condensed water to enter. The steam raised in the lower boiler rushes through this opening in the iron partition, and acts upon the upper boiler so as to heat it and evaporate it to a certain degree, and this steam being condensed falls down upon the cover of the sloping cover of the lower boiler, and runs off through the waste pipes *e* to the drain, as shown in the figure.

The waste water being warm, imparts heat to the brine as it is conducted along the pipe *p*, which is the pipe of a force-pump for forcing the raw brine from the brine well to the upper boiler, and which is laid along the waste drain *f* for this purpose: *nn* are rakes with iron handles working through air-tight stuffing-boxes *b*; these are for the purpose of raking the salt to the fore part of the boiler where it is taken out at the man hole *m*.

The lower boiler must be provided with a safety

valve in the usual way. Alderson on the Steam Engine

Mechanical Processes.

The following Table shows the result of a course of experiments to determine the amount of impurities in different descriptions of salt, by Dr. Henry, and published by him in the *Philosophical Transactions* for 1810. These experiments were undertaken principally with a view of ascertaining the comparative qualities of different foreign and British salts.

Dr. Henry's analysis.

From an examination of the results in the last two columns, the total amount of impurities, and the quantity of muriate of soda contained in each variety of common salt, may be immediately seen; and from these it appears that the foreign bay salt is purer, generally speaking, than salt which is prepared by the rapid evaporation of sea water, but that it is contaminated more than twice as much as the *stoved* and *common* salt of the Cheshire district.

(617.) TABLE showing the Amount of the Impurities in different Kinds of Salt.

Kind of Salt.		1000 parts of which consisting of							
		Insoluble matter.	Muriate of lime.	Muriate of magnesia.	Total earthy muriates.	Sulphate of lime.	Sulphate of magnesia.	Total sulphates.	Total impurities.
Foreign bay salt.	St. Ube's	9	a trace	3	3	23½	4½	28	40
	St. Martin's	12	do.	3½	3½	19	6	25	40½
	Oleron	10	do.	2	2	19½	4½	23½	35½
British salt from sea water.	Scotch (common)	4	..	28	28	15	17½	32½	64½
	Scotch (Sunday)	1	..	11½	11½	12	4½	16½	29
	Lymington (common)	2	..	11	11	15	35	50	63
	Ditto (cat)	1	..	5	5	1	5	6	12
Cheshire salt.	Crushed rock	10	1½	1½	1½	6½	..	6½	16½
	Fishery	1	1½	1½	1	11½	..	11½	13½
	Common	1	1½	1½	1	14½	..	14½	16½
	Stoved	1	1½	1½	1	15½	..	15½	17½

(618.) TABLE showing the Amount of the Salt Duty per Annum from 1820 to 1825, when the Duty was repealed.

Salt duty.	Years.	Duty per Bushel.	Amount.
	1820	15s.	£1,529,862
	1821	15	1,553,841
	1822	15	1,490,007
	1823	2	385,325
	1824	2	220,098
	1825	2	8,895
	1826	Duty repealed.	

Epsom salts.

(619.) *Epsom Salts*, or sulphate of magnesia, would hardly have been thought of sufficient general interest as a British product to be introduced in this place; but it is so intimately connected with the preceding article, that a few lines descriptive of the process of its manufacture will not, we trust, be considered misplaced. In order to illustrate this, it will be necessary to describe a little more particularly than we have done, the process followed at Lymington, in Hampshire, in the formation of common salt. As the climate there is warmer than in most other parts of our coast, advantage is taken of this circumstance to concentrate the sea water by spontaneous evaporation to about one-sixth of its bulk, before admitting it into the boilers; and one difference in the subsequent process is, that the salt is not there *fished* out of the boilers and drained, as we have before

described, but the water is entirely evaporated, as by the patent apparatus, and taken out once every eight hours and removed into troughs having holes in their bottoms. Through these it drains into pits made under ground, which receive the liquor called *bittern* or *bitter liquor*. Under the troughs, and in a line with the holes, are fixed upright stakes, on which a portion of salt, that would otherwise have escaped, crystallizes, and forms, in the course of ten or twelve days, on each stake, a mass of sixty or eighty pounds. These lumps are called *salt cats*. They bear the proportion to the common salt made from the same brine of one ton to one hundred.

From the mother-brine or bitter liquor, which has drained into pits, the sulphate of magnesia is made during the winter season, when the manufacture of salt is suspended, in consequent of the want of the temperature required for the spontaneous evaporation of the sea water. The process is a very simple one. The bitter liquor from the pits is boiled for some hours in the pans which are used in summer to prepare common salt, and the impurities, which rise to the surface, are removed by skimming. During the evaporation, a portion of common salt separates; and this, as it is too impure for use, is reserved for the purpose of concentrating the brine in summer. The evaporated bitter liquor is then removed into wooden coolers, eight feet long, five feet wide, and one foot deep. In these it remains twenty-four hours, during which time, if the

Manufac-
tures.

weather proves clear and cold, the sulphate of magnesia, or Epsom salt, crystallizes at the bottom of the coolers, in quantity equal to about one-eighth of the boiled liquor. The uncrystallizable fluid is then let off through plug-holes at the bottom of the coolers, and the Epsom salt, after being drained in baskets, is deposited in the store-house. This is termed *single* Epsom salts, and after solution and a second crystallization, it acquires the name of *double* Epsom salts. Four or five tons of sulphate of magnesia are produced from a quantity of brine which has yielded one hundred tons of common and one ton of cat salt.—*Philosophical Transactions*, 1810.

Saltpetre Works.

Saltpetre,

(620.) Although, in consequence of the facility with which England is supplied with this important element of war from her possessions in the East Indies, and her trade with China, we have no saltpetre works in this Country, yet it would perhaps be considered an improper omission if we did not devote a few lines to an explanation of the depositories of the components of this salt, and the processes followed in its manufacture. Saltpetre may be esteemed both as a natural and artificial product, although in its former character we must consider it as a recent formation. It occurs in two different repositories, *viz.* in limestone and in vegetable soil. The calcareous repository is a peculiar variety of secondary flætz limestone, or calcareous tufa or chalk, or indurated marl. In these rocks it occurs in a thin, granular crust, or in an efflorescence of minute specular crystals, overspreading the outside, and particularly lining the insides of caverns both natural and artificial; and, hence, probably, is derived its ancient name saltpetre, or salt rock. Calcareous strata containing nitre are found in many parts of the globe, but the most celebrated repository of native nitre is the Pulo of Molfetta, in the Kingdom of Naples. The Pulo is a deep cavity in the form of an inverted cone, produced by the falling in of several natural caverns, and communicating with other lateral caverns, both natural and artificial. The whole of these caves, when attention was first called to them by the Abbé Fortis, were covered with an efflorescent crust of saltpetre more than an inch in thickness, which after being scraped off was again renewed in the course of a few days in constant succession. Similar formations, on a less scale, are obtained in many other places. The other source from which nitre is derived is vegetable soils. In Spain, Hungary, in some parts of France, and various other Countries, very rich productions of nitre are obtained from the natural soil; in others, ground is artificially prepared for the purpose; the surface is swept or gathered at intervals and lixiviated, the liquor is then boiled down, and affords, by cooling, a quantity of nitre mixed with common salt, varying of course according to circumstances.

obtained
from
caverns,

and from
vegetable
soil.

Processes
employed in
lixiviation.

The process of lixiviation is performed in the following manner. Several cart-loads of nitrous earth are mixed as accurately as possible with the requisite quantity of alkali, either in the form of wood ashes or pulverized potash; the proper quantity or proportion being first determined by experiment on a small weight of the earth.

Several large casks, with perforated false bottoms, are now filled with the prepared earth, laid on very lightly, after which as much river water is poured in as the

vessels will hold. In two or three hours' time the cock at the bottom of each cask is turned, and the liquor is allowed to drain out during the remainder of the day. The casks of a second series, charged with earth as before, are now filled up with the first lixivium, and after standing for a few hours the liquor thus concentrated is drawn off in the manner just described. By a similar process on the third day, a lixivium thrice as strong as the first is obtained, which is now sufficiently concentrated to be boiled down. The contents of each series of casks are lixiviated twice more, and the weak solutions thus obtained are employed instead of water in the first and second lixiviations of fresh parcels of earth.

Mechanical
Processes.

The boiling down and evaporation next succeeds. Boiling and The lixivium, containing nitrate of potash, the muriates of evaporating potash and soda, with probably a few other salts, and various earthy and other impurities, is put into a large boiler like a salt-pan, and heated nearly to ebullition; it is then clarified by the addition of bullock's blood or solution of glue, the impurities as they appear on the surface being carefully skimmed off. When no more froth rises of itself, a little lime-water is added, which coagulates the remainder of the blood and glue, and thus completes the clarification. It is now boiled for several hours, and the muriates of potash and soda, as they are deposited, are withdrawn by a perforated ladle. When the liquor is so concentrated that a few drops crystallize readily on being dropped on a cold iron, it is laded out into a vat, where it remains a short time to deposit the common salt and impurities still floating in it: thence it is transferred to a large wooden or metallic crystallizing basin, in which it remains closely covered up during from three to six days, according to the temperature of the air; at the expiration of which period the fluid mother-water is poured out and returned to the nitre bed, and the salt, deposited in a confused, crystalline mass of opaque, dirty white, is broken to pieces and set to drain, after which it is brought to market, or delivered in to the Government stores as rough nitre, or nitre of the first boiling.

In order to refine the rough nitre, the old practice Refining was to subject it to two more successive boilings and process. crystallizations; by this method, however, a very considerable proportion of the nitre was left in the mother-waters; no inconsiderable share was volatilized by the heat required for evaporating the solution when it had nearly acquired the due degree of concentration; and, besides, a great expense of both time and fuel was incurred. The modern method of refining this salt was invented in France a few years ago, and is now considered as brought nearly to perfection. It is thus effected:

The rough nitre is broken to small fragments by wooden mallets, and is then put into a wooden tub with 20 per cent. by weight of cold water; in this state it remains for six or seven hours, being occasionally well stirred up that the water may have free access to every part. The water is now let out by a hole at the bottom of the vessel, and carries with it in the solution all the deliquescent salts, and the greatest part of the muriates of soda and potash, together with some nitre. When the whole of the liquor is drained off, 10 per cent. more of water is added and well mixed with the nitre for an hour's time, when it is discharged in the same manner as the first. Lastly, 5 per cent. of water is poured in and run off again almost immediately after. The nitre thus washed, after being well drained,

Manufac-
tures.

is put into a boiler with half its weight of water, and boiled till a pellicle forms on its surface; the liquor is then discharged into a large leaden cooler, and stirred about with rakes till it is quite cold, by which manipulation the salt is deposited in small crystalline needles. It is now taken out of the liquor with a perforated ladle and well drained; after which it is washed with 5 per cent. of cold water and again drained: being then spread out on a large table, it dries in a few hours, and is, lastly, heated over a fire in large basins for two or three hours, at a temperature not exceeding 120° Fahrenheit, taking care to stir it all the while. By this treatment it is perfectly purified and brought to the consistence of fine sand, and is now ready to be manufactured into gunpowder. Aikin's Dictionary.

(621.) TABLE showing the Quantity of Saltpetre imported, exported from the United Kingdom, and cleared for Consumption, from 1820 to 1831.

Years.	Saltpetre.					
	Quantities.			Rates of duty per Cwt.	Net Revenue.	
	Imported.	Exported.	Cleared for Con- sumption.			
	Cwts.	Cwts.	Cwts.	s.	d.	£.
1820	196,614	71,618	58,080	0	6	1,926
1821	244,886	87,431	52,496	,,		2,360
1822	133,166	66,967	89,946	,,		2,958
1823	151,932	44,587	141,632	,,		4,167
1824	154,750	53,041	135,606	,,		3,857
1825	97,637	50,691	112,443	,,		3,227
1826	131,170	52,300	122,063	,,		3,379
1827	201,085	47,269	147,537	,,		4,017
1828	204,841	69,067	171,770	,,		4,748
1829	176,490	46,594	155,095	,,		4,181
1830	144,646	14,894	143,057	,,		3,691
1831	175,938	30,164	155,499	,,		4,140

Soap Works.

(622.) Common soap is composed of any kind of oil, either vegetable or animal, with fixed alkali, either potash or soda. Besides these substances, lime is essential to give the alkali the requisite degree of causticity; and in those soaps in which the alkali employed is potash, the addition of common salt is also required. Soap is manufactured in this Country principally from tallow, or any other fat, and the alkali made use of is either barilla or pearl-ash, or a mixture of the two, according to the price and practice of the manufacturer. But as potash alone will not make a stiff soap, recourse is had to the action of common salt, which, when added after the potash and oil are united, produces a separation of the compound from the water incorporated with it, hardens and renders it equal to the soda soaps.

Process for
making
white soap
with pot-
ash.

The following is the usual method of making the common white and yellow soap used in domestic purposes.

White hard soap is generally made with three separate charges of lie. The potash (when this alkali is used) is previously dissolved with water in a small boiler with a little fire, and the solution is poured over a vat containing common wood-ashes mixed with lime,

which gives the first and strongest lie. As soon as this has run off, the ashes are turned, more lime is added, and water is pumped on, which forms the second or weak lie. The large boiler is then charged with the tallow, and about two-thirds of the strong lie being added, a moderate fire is kept up to incorporate the materials, which is known by their running into a stiff glue. If this does not take place in about seven hours, (with twenty-nine hundred weight of tallow in the boiler,) more alkali must be added. The tallow is then termed *killed* or saturated; the fire is drawn, and the materials are allowed to remain at rest for a short time.

Common salt is now thrown in, and stirred up with long poles till it is thoroughly incorporated, and till the matter changes from a dark-coloured glue to a thin soapy substance. A brisk fire is then made, and the materials are boiled for a few minutes, when the fire is again drawn and the materials in the boiler are allowed to settle for an hour and a half, during which the spent lies sink to the bottom of the boiler and are pumped off. The second operation begins by raising the fire and adding to the soapy mass the weak lie, which is to be managed in the same manner as the first; this again brings it to the state of a glue, which a very little salt will restore to the saponaceous state, and after boiling and cooling, the second lies are pumped off.

In the third operation, the third part of the strong lie which was reserved is added, which, as before, changes the mass to a thick glue, and must be again grained with salt. The contents are then boiled strongly for three hours, more or less, till by taking samples occasionally with a trowel, the soap is felt sufficiently hard and dry to the touch, and the lie will be seen to run off quite clear from the soap on the trowel, leaving the latter in sound lumps.

The boil of soap is then finished by pumping off the spent lie and scraping off a quantity of light froth from the top of the soap. The soap is then fit for *framing*, which is a perfectly simple process. The frames are wooden troughs, with a movable bottom, into which the soap is poured while still fluid, and allowed to remain for three or four days till it is stiff enough to be handled without sinking in. The soap is then taken out and cut into long prisms with a brass wire, and kept for some time in an airy room till it has become of the requisite hardness, and is then fit for sale.

In making yellow soap, a quantity of rosin is added to the oil and tallow. The lie is prepared in a similar vat, and the arrangement of the processes is in other respects the same as in forming white soap.

With regard to the proportions of ingredients, it is reckoned that sixteen bushels of good wood-ashes are equal in alkali to one hundred weight of the best pearl-ash, and that this latter quantity will saturate two hundred weight of tallow, and produce three hundred weight one quarter of soap; so that twelve parts of tallow will make twenty of soap: also twelve bushels of wood-ashes are equal to one hundred weight of barilla; and the latter quantity will saturate one and a half hundred weight of tallow. A boil of twenty-nine hundred weight of tallow with ten hundred weight of barilla and five hundred weight of pearl-ash requires about eight hundred weight of common salt. The common salt seems to have another use in soap making, in addition to the one we have already described, *viz.* that of promoting the grain-ing or separation of the soap from the spent lie, which it does prooably by simply extracting the watery part.

Mechanical
Processes.

Manufactures.

In this way it is as much used in the soda as in the potash soaps; and in each it considerably hastens the process, but it is by no means essential, as it appears to be seldom used where barilla or soda is the sole alkali.

Process for making soap made with kelp and tallow.

Hard soap is made in Scotland chiefly with kelp and tallow. That crude alkali rarely contains more than from one to five per cent. of free soda, mixed with some sulphate and hydrosulphate, and nearly 33 per cent. of muriate of soda.

To every ton of kelp broken into small fragments, about one-sixth of new-slacked lime is added. The whole after mixture is put into a large tub called a *cave*, having a perforation at the bottom shut with a wooden plug. Upon the materials, water is very slowly poured, and the liquor, after digestion, is suffered to run slowly off into a reservoir sunk in the ground. The first portion, or lie No. 1, is of course the strongest, and is reserved for the last operation of soap-boiling. A gallon of this lie, of the average strength, contains 1000 grains of real soda, so that one pound of alkali is present in seven gallons of lie. The second portion run off contains 800 grains in one gallon, equivalent to a pound in 8 $\frac{1}{4}$ gallons. The third contains 600 grains per gallon, or one pound in 11 $\frac{1}{2}$ gallons, and the fourth 200 grains, or one pound in 35 gallons. The last is not employed directly, but is thrown on a fresh mixture in the cave to acquire more alkaline strength.

Six days are required to make one boiling of soap in which two tons or upwards of tallow may be employed. The lies 2 and 3 mixed are used in the beginning diluted with water on account of the excess of sea salt in the kelp. A quantity of lie is poured on the melted tallow and the mixture is boiled, while a workman agitates the materials to facilitate the combination. The fire being withdrawn, and the aqueous liquid having subsided, it is pumped off and a new portion is thrown in. A second boiling is given, and so on in succession. Two or three boilings are performed every six days, constituting twelve or eighteen operations in the whole. Towards the last, the stronger lies are made use of, but as soon as the workman perceives the separation perfect, the process is stopped and the soap is lifted out and put into moulds to dry.

Another process for white soap.

The following is the process given by Macquer for making hard white soap from tallow and soda.

A lie is prepared with two parts of good Spanish soda, and one of quicklime, boiled in a vessel with twelve times as much water, which must be filtered and evaporated until an ounce phial will contain one and three-eighths of an ounce of this concentrated lie. Mix with 200 gallons of lie ten hundred weight of the best tallow, which must be melted over a moderate fire and at the end of two hours drawn away, and the pan allowed to settle for about the same length of time, when the lie may be drawn off. Two or three boilings may be given every day, which must be continued day after day until the whole assume the appearance of a curdy mass. A portion is then examined by squeezing it between the finger and thumb, and if it has the appearance of thin hard scales it is fit for finishing. If, on the contrary, it is of a soft consistency, appearing greasy, and sticks to the finger, more lie must be added, and if that does not sufficiently harden it, another boiling must be given.

When the soap is found to assume the light appearance of hard scales, it must have another boiling, and after being cooled down by two or three pails of lie, must remain two hours, and the lie be again pumped

from it. The next operation is that of boiling it with about 80 or 90 gallons of water, the whole being well incorporated together by stirring; 10 gallons of a solution of salt, of one part of salt in three of water, are then added, which has the effect of separating the soap from the water. The fire is then withdrawn, and after the whole has stood for half an hour, the water is pumped off, which will carry with it the remainder of the alkaline lie of the former boiling.

This operation is termed the *first washing*; a second must be given by 60 or 70 gallons of water more; and in some cases a third, according to the degree of consistency required in the soap. The soap must then be left to stand for twelve or fourteen hours, when it will be ready for the operation of framing already described, which completes the manufacture. Fine white soap is made with one part of the above lie with two of oil of olives, or oil of sweet almonds, which must be stirred occasionally with an iron spatula till it is thick and white. The ingredients gradually combine, and in seven or eight days a firm and very white soap is obtained.

(623.) *Soft soap*.—This is a compound of fats or oils with potash alone, and does not in consequence acquire the consistence of hard soap. There are three kinds known in commerce: soap from oleaginous seeds, called *green soaps*; from hog's lard, termed *toilette soaps*; and others from rapeseed.

Manufacturers of green soap prepare their potash lies as those of hard soap do their soda lies, and conduct their operations in the same way till the oils are added. In this state the soap resembles an unguent; it contains an excess of oil, is white, and nearly transparent. After tempering the fire, they keep continually stirring the bottom of the caldron with large spatulas, and add by degrees new lies, perfectly caustic and somewhat stronger than the first, by which the saturation of the oil is effected and the soap becomes transparent. The fire is continued until the soap is of a suitable consistency, after which it is run into barrels for sale.

The following particulars on the manufacture of soft soap are given in Dr. Ure's *Dictionary*, for which he states himself to be indebted to an eminent manufacturer at Glasgow.

273 Gallons of whale oil and 4 hundred weight of tallow are put into a boiler with 252 gallons of potash lie, whose alkaline strength is such that one gallon contains 6600 grains of real potash. Heat is applied when the mixture froths up very much, but is prevented from boiling over by a wooden crib which surmounts the iron caldron. If it now subside into a doughy magma, it shows that the lie has been too much concentrated, its right appearance being a thin, gluey mass. There is next poured in two measures of a stronger lie holding each 21 gallons, (containing per gallon 8700 grains of real potash,) and after a little interval, another two measures, and so on progressively until 14 measures have been added in the whole. After suitable boiling without agitation, the soap is formed, amounting in all to 100 firkins of 64 pounds each, from the above quantity of materials. Rape oil forms a hard soap, neither so consistent nor so white as that of olive oil. Hempseed produces a green-coloured soap, which may be reduced to a paste by a small portion of water. The soaps prepared with oils produced from the beech-mast and clove July flowers are of a clammy glutinous consistence, and generally of a greyish colour. Nut oil forms a soap not proper for the hands; it is of yellowish-white colour and of a moderate degree of consistence, unctuous

Mechanical Processes.

Manufac-
tures.

gluey, which it continues to be after exposure to the air. The soap of which linseed oil forms a constituent part, is at first white, but changes to yellow in a short time by exposure to the air: it possesses a strong odour, is unctuous, clammy glutinous, does not dry in the air, and softens with a very small quantity of water.

From what has been said, we may conclude that the soaps prepared with desiccative oils are of a very indifferent quality, that they remain always glutinous and readily change their colour on exposure to the atmosphere.

(624.) The following are the quantities of hard and soft soap charged with duties of Excise in the United Kingdom, and the net produce of the duty in each year, from 1820 to 1831.

Years.	Quantity of hard Soap charged with duty.	Quantity of soft Soap charged with duty.	Net produce of duty.
	lbs.	lbs.	£.
1820	82,413,223	6,903,356	928,602
1821	87,717,693	7,470,030	1,023,534
1822	89,672,508	7,576,422	1,120,989
1823	87,071,456	8,226,922	1,147,660
1824	100,270,453	9,297,485	1,194,361
1825	102,623,165	8,910,504	1,199,364
1826	96,859,694	7,278,446	1,144,539
1827	104,371,285	9,646,477	1,230,663
1828	108,193,606	10,024,665	1,201,754
1829	103,041,941	9,068,918	1,151,906
1830	117,157,916	10,209,519	1,249,684
1831	108,956,030	9,641,907	1,138,262

Sulphur Works.

Sulphur

(625.) Sulphur occurs native in many places, particularly in the Kingdom of Naples, and is frequently nearly in a state of purity, or slightly combined with earths. The whole preparation which it requires, therefore, in this case, to render it fit for the purposes of commerce, is to free it from its earths by distillation.

In other cases it is obtained artificially in the roasting of copper ore, as at the celebrated Paris mountain copper mine in the Island of Anglesea. There works for that purpose are constructed on a large scale. At the foot of a low but a steep ridge of rock are constructed masses of masonry, not unlike high blast-furnaces, except that the top is capped with a dome of brickwork, from which proceeds a horizontal flue, about the size of a common chimney, which terminates in a square or oblong brick chamber, built at the top of the rock. Some lighted fuel is introduced by means of a door in the dome of this roasting furnace, and a few baskets full of ore, broken into moderately small pieces, are thrown on, fresh parcels of ore being added from time to time; as the preceding parcels get lighter, a sufficiency of air for the slow combustion required in this process is let in by means of a door at the bottom of the kiln, which also serves for taking out the ore when properly roasted; the part of the sulphur which escapes combustion rises in vapour, and collects in the dome, (the door of which is only opened to admit fresh charges of ore,) whence it passes through the flue into the chamber, where it presently concretes, lining the sides and roof; each chamber has a door, by means of which, about once in six weeks, it is cleared of the sulphur. This rough sulphur is in spongy, pulverulent crusts, of a dirty greyish-yellow colour. For its purification it is melted in a boiler, the impurities are got rid of by skimming and subsidence, and the fluid mass is then laded into cylindrical moulds to form the common roll sulphur or brimstone, or into cones about two feet high, forming the loaves of sulphur. The impure dregs are also sold in the shops under the name of *sulphur vivum*. The sulphur which is procured in the roasting of ores, especially those of copper, is apt to contain, besides earthy impurities, a very considerable proportion of arsenic, while, on the other hand, the volcanic sulphur in general, and that of Sicily in particular, is entirely free from this contamination; which is the cause of the universal preference given by the manufacturers of sulphuric acid to Sicilian over English sulphur.

Mechanica
Processes.
obtained by
roasting
copper ore.

(626.) TABLE, showing the Quantities of Brimstone imported and exported from the United Kingdom, and cleared for Consumption, from 1820 to 1831.

Brimstone.									
Years.	Importation.	Exportation.	Consumption.	Rates of Duty per Cwt.			Gross Revenue.	Drawbacks on Brimstone used in making Oil of Vitriol, and on Brimstone exported. Repayments on over Entries, &c.	Net Revenue.
				Unrefined.	Refined.	In Flour.			
	Cwts.	Cwts.	Cwts.	£. s. d.	£. s. d.	£. s. d.	£.	£.	£.
1820	93,003	14,121	112,057	0 15 0	1 0 0	1 3 9	85,221	61,924	23,297
1821	113,844	6,122	124,633	"	"	"	95,648	68,568	27,080
1822	99,121	6,717	151,657	"	"	"	115,670	77,060	38,610
1823	172,495	2,293	153,841	"	"	"	117,637	95,370	22,267
1824	181,317	3,472	165,871	"	"	"	126,332	102,269	24,063
1825	218,722	4,860	268,433	0 0 6	0 6 0	0 9 9	75,306	118,830	{ Excess of payment 43,524
1826	251,981	6,817	233,093	{ Drawback on making Oil of Vitriol	on Brimstone used	ceased.	5,903	13,821	do. 7,918
1827	218,359	16,385	207,462	...	...	...	5,275	32	5,243
1828	279,867	1,798	289,974	...	...	...	7,295	7	7,288
1829	302,084	941	314,182	...	...	...	7,886	4	7,882
1830	242,726	8,946	264,436	...	...	...	6,653	24	6,629
1831	289,446	4,992	296,095	...	...	...	7,480	28	7,452

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tures.*Vitriol Works.*Manufac-
ture of sul-
phuric acid.Process
described
by Dr.
Aikin.

(627.) *Sulphuric acid or oil of vitriol.*—Sulphuric acid is largely employed in various branches of the Arts and Manufactures. It was formerly wholly obtained by distillation from sulphate of iron, and this practice is still followed in some parts of the Continent; but the process generally adopted in this Country is by the combustion of sulphur and nitre, and is described by Dr. Aikin to consist of, first, having a chamber constructed of framework and lined with strong sheet lead, the only opening being a small door, made to shut very close, the bottom of which is a little higher than the floor of the chamber. Water is poured into this chamber till it rises to the height of an inch or two from the floor, and a stand is introduced, in which is placed an earthen pot, containing a few pounds of sulphur and of nitre, in the proportion of from eight to ten of the former to one of the latter; this mixture is set on fire by means of red-hot iron, and the door immediately closed; at the end of about six hours another charge of sulphur and nitre is introduced, which, after a similar interval, is replaced by a third, and so on, without intermission, for a fortnight or three weeks. At the end of this time, the water in the chamber is sufficiently acidulated, and is then transferred to a leaden boiler, where the greater part of the water is evaporated; in proportion, however, as the acid becomes more concentrated, it has the more tendency to corrode and dissolve the lead of the boiler; therefore, before it arrives at this state it is transferred into large, green glass retorts, where a degree of heat is supplied sufficient to drive off almost the whole of the water. As the acid becomes stronger it also becomes clearer and less coloured, in consequence of a portion of the acid reacting upon the impurities with which it is tinged and thus destroying them.

When the acid is thus brought to the required density and clearness, it is poured out of the retorts into large globular, glass bottles, surrounded with wickerwork and lined with straw, called *carboys*. In this state it is brought into the market.

By Dr. Ure.

Dr. Ure's description differs a little from the above and is somewhat more minute. The ordinary form of the sulphuric and lead chamber he states to be a parallelopiped, about seventy feet long, ten or twelve high, and fifteen wide. At the middle height of one end, a small oven is built up with a cast iron sole, having a large lead pipe, ten or twelve inches diameter, proceeding from its arched top into the end of the lead chamber. On the sole the sulphur is burned, the combustion being aided, when necessary, by heat applied from a little furnace below it. Above the flaming sulphur a cast iron basin is supported in an iron frame, into which the nitre, equal to one-tenth of the sulphur, is put, with a little sulphuric acid. The combustion of the sulphur is regulated by a sliding door in the oven. In the roof of the remote end of the large chamber a small orifice is left for the escape of the atmospherical azote and other incondensable gases. This apparatus is used for the continuous process. But there is another, or that of the *intermitting* combustion, which is worthy of notice. Long flat trays, containing the sulphur and nitre, are introduced into the interior of the chamber, or into the oven, and fire is applied to the materials. When the sulphur is burned, and the chamber is replete with sulphurous and nitrous acids, a stream of water is thrown in, in determinate quantity, by a small pipe at the side. This causes a tumultuous

VOL. VII.

motion among the gases and the atmospheric oxygen, which favours the mutual reaction. As the steam condenses, the sulphuric acid falls with it. After some time, the chamber is aired by opening valves of communication with the external atmosphere. The operation is then commenced anew.

Instead of using nitre, nitrous gas, disengaged from nitric acid by sugar or saw-dust, is introduced into the chamber containing the fumes of burning sulphur, whereby the chemical reaction above described is produced, and then steam is thrown in to complete the process and condense the sulphuric acid. The bottom of the lead chamber should never be covered with pure water, but even in the first operation with a dilute acid, introduced on purpose. When nitrous acid comes into contact with water and an excess of atmospheric oxygen, it is converted into nitric acid and nitrous gas. This aeriform body gets more oxygen and changes to nitrous acid, and thereafter to nitric. Hence a chamber with its bottom covered with water will, in some cases, fail in producing any sulphuric acid at all. Water moderately charged with sulphuric and sulphurous acids prevents the transition of nitrous into nitric acid, and allows the process of acidification of the sulphur to go on freely.

Ure's Dictionary.

(628.) *Sulphate of zinc or white vitriol.*—The impure sulphate of zinc, called in commerce white vitriol, is of a bluish-white colour, with ochrey stains externally: it has a granular crystalline texture like loaf sugar, and is in irregular, lumps or masses. The English white vitriol is prepared for the most part by direct solution of a metallic zinc in sulphuric acid, and is therefore purer than the foreign, though it still contains a quantity of iron. Both kinds may be considerably, though not entirely, purified by solution in water, and then abandoning the liquor to spontaneous evaporation in an open vessel containing some granulated zinc, the sulphate of lead will subside to the bottom, and other foreign sulphates will be decomposed by the metallic zinc. The saline mass, when dry, is to be lixiviated with cold water, and the clear filtered solution, after due evaporation, will afford regular crystals of sulphated zinc.

Manufac-
ture of
white
vitriol.

(629.) *Sulphate of copper or blue vitriol.*—This is not manufactured at large in sufficient quantity to give the process a place in this general list of what we have called Works. If copper filings or clippings of thin sheet copper be put into a glass vessel with about twice their weight of sulphuric acid, and the mixture be heated, solution will take place. When this begins, much sulphuric acid gas is given out, (and this is a very convenient way of procuring this gas,) and at last the whole is dissolved into a dark-coloured liquor, except a small quantity of black residue, which is the sulphuret contained more or less in all common copper, and by dilution in water the liquor becomes a fine blue. This solution, by due evaporation and cooling, furnishes crystals also of the same colour, and, when regular, which, however, they seldom are, they assume a rhomboidal shape, which is the blue or Roman vitriol of commerce.

Blue vitriol.

(630.) *Sulphate of iron or green vitriol.*—This salt is of extensive use in the Art of dyeing and other processes. It is not commonly formed by a direct combination of its natural ingredients, but is obtained from various kinds of native sulphates of iron or pyrites.

Manufac-
ture of
green vitriol.

The first English work of this kind was established at Deptford, where it is still carried on; and several large

Manufac-
tures.

works are also employed in the same manufacture in Durham and Northumberland. The process of forming this salt in 1678 is described by D. Colwell, Esq., in vol. xii. of the *Philosophical Transactions*, and it is extraordinary to find amongst the numerous changes which the Arts and the Manufactures of England have undergone in this series of years, how little difference there is in this one in particular. It is unnecessary to transcribe Mr. Colwell's account, but by referring to it the reader will find how little it differs from the following, communicated to Dr. Aikin, as descriptive of the modern process.

The usual mode of manufacturing copperas on the Rivers Tyne and Wear, is by exposing iron pyrites, (there called *brasses*.) which are found in the collieries, to the influence of the atmosphere. For this purpose, a situation is chosen, inclining towards the river, of a natural strong clay. After the soil is taken off, gutters are cut in different directions, and wells of about five or six feet deep and two or three in diameter are sunk where the gutters terminate. Upon this surface the brasses are laid to the thickness of four or five feet. The vitriolization shows itself in a white efflorescence, which is washed off by the rain into the gutters, and conveyed by pipes from the wells to a reservoir, from which there is a pipe of communication to the boiler. This is a leaden vessel generally about seven feet deep, twelve or fourteen long, and six or seven wide. Here the liquor is evaporated for six days, during which time as much of old iron is added to it as it will dissolve. It is then run into a crystallizing vessel, and remains there for five weeks, at the end of which time the mother-liquor is run into a reservoir, and pumped back into the boiler, the crystals being removed, which after being drained are packed in hogsheads for sale. A single boiling from a boiler of the above dimensions yields from five to eight tons of copperas, according to the strength of the liquor.

In 1830, an account was published in the *Repertory of Arts*, vol. liv., describing the principles of a French patent for the manufacture of this salt, but we are not aware that any works founded upon it have been adopted in this Country.

Vinegar Works.

Manufac-
ture of
vinegar.

(631.) *Vinegar* was, doubtless, as its name imports, first made from wine, and is always so made in wine Countries. It is there prepared by adding wine lees to wine, which excites a new fermentation that is kept up till the whole is changed to vinegar; but in this Country vinegar is generally made from malt, the usual process being as follows.

A mash of malt and hot water is made, which, after infusion for an hour and a half, is conveyed into coolers a few inches deep, and thence, when sufficiently cooled, into large and deep fermenting tuns, in which it is mixed with yeast, and kept in fermentation for four or five days. The liquor (which is now a strong ale without hops) is then distributed into smaller barrels, set close together in a stoved chamber, and a moderate heat is kept up for about six weeks, during which the fermentation goes on equally and uniformly till the whole is soured. This is then emptied into common barrels, which are set in rows (often of many hundreds) in a field in the open air, the bung-hole being just covered with a tile to keep off the wet, but to allow a free admission of air. Here

the liquor remains for four or five months, according to the heat of the weather, a gentle fermentation being kept up till it becomes perfect vinegar. This is finished in the following way. Large tuns are employed with a false bottom, on which is put a quantity of the refuse of raisins or other fruit left by the makers of raisin and other home-made wines, technically called *rape*. These rape tuns are worked by pairs; one of them is quite filled with the vinegar from the barrels, and the other is only three-quarters full, so that the fermentation is excited more easily in the latter than in the former, and every day a portion of the vinegar is laded from one to the other till the whole is completely finished and fit for sale.

Vinegar, as well as fruit wines, is often made in small quantities for domestic uses, and the process is by no means difficult. The materials may be either brown sugar and water alone, or sugar with raisins, currants, and especially ripe gooseberries. These should be mixed in the proportions which would give a strong wine put into a small barrel, which it should fill about three-fourths, and the bung-hole should be very loosely stopped. Some yeast, or what is better, a toast sopped in yeast should be put in, and the barrel set in the sun in summer, or a little way from a fire in winter, and the fermentation will soon begin. This should be kept up constant but very moderate, till the taste and smell indicate that the vinegar is complete. It should then be poured off clear and bottled carefully, and it will keep much better if it is boiled for a minute, cooled and strained before bottling.

The following is the quantity of British vinegar made and paying duty from 1820 to 1831:

Years.	Number of Gallons.	Amount of Duty.
1820	2,497,468	£40,586
1821	2,754,004	43,802
1822	2,004,639	45,638
1823	2,406,563	47,124
1824	2,360,426	46,341
1825	2,340,812	45,518
1826	3,028,891	25,136
1827	2,967,864	24,746
1828	2,652,867	24,475
1829	2,558,798	22,541
1830	2,159,858	17,862
1831	2,689,747	19,313

Whale Oil Works.

(632.) Amongst the various objects of British manufacture, and resting on British enterprise, the whale fisheries are by no means unimportant. The fishery itself is a subject of great interest, and is described with great perspicuity by Mr. Scoresby, in his *Account of the Arctic Regions*, published in 1820. It is, however, not within our limits to enter into a description of this first process towards obtaining the oil. We must consider the fish as already caught and stowed in the whale ships, and that these have returned to port with their blubber to be converted into oil fit for use. For the following description of this process we are indebted to vol. ii. of Mr. Scoresby's Work above referred to.

Description of the premises, apparatus, &c.—On the margin of a wet-dock, canal, or other sheet of water, communicating with that wherein the whale-fishing ship discharges her cargo, are usually provided the necessary

Mechanical
Processes.

Whale
fishery.

Description
of premises
and appa-
tus.

Manufac-
tures.

Copper.

premises for reducing the blubber into oil, consisting commonly of the following articles.

A copper vessel or boiler, from three to six, or even ten or more tons capacity, of a circular form in the horizontal view, and elliptical in the perpendicular section, is fixed at the elevation of six to ten feet above the ground, provided with an approximate furnace, and covered with a tiled or slated shed. Some of these *coppers* have a sudden depression in the bottom, into which the refuse of the blubber subsides when it is sufficiently boiled; and at the elevation of a foot or eighteen inches above the bottom, (higher than the cavity usually occupied by the refuse,) is a grating and conducting pipe, through which, on turning a stop-cock, the greater part of the oil in the copper is conveyed into an adjoining cooler.

Back.

On the same, or on a little lower level than that of the copper, is fixed a square or oblong *back* or cooler, built generally of wood, but sometimes of brick or stone lined with lead or cement, capable of containing from ten to twenty tons of oil or upwards. Adjoining to this is another back, sometimes a third, and occasionally a fourth or fifth, each placed a little lower than the one preceding it, so that the lowest shall stand with its base about two or three feet above the level of the ground. In some very modern works, the coolers are all fixed at the same elevation. Each of the backs is provided with one or more stop-cocks on the most accessible side for convenience of drawing the oil off into casks.

Starting
back.

Altogether above the level of the copper, and immediately adjoining it, on the side directed towards the river or canal, an oblong wooden cistern, called the *starting back*, is usually erected, for containing blubber, which ought to be a vessel of equal or nearly equal capacity to that of the copper. It is generally provided with a crane, which, with a winch, or other similar engine attached, is so contrived as to take casks, either from the quay or from a lighter by the side of the quay, and convey them at once to the top of the starting back. Over this vessel is extended a kind of railing or *gauntree*, on which the casks rest, without being injured, and are easily movable.

The starting back being elevated two or three yards above the level of the ground, occasionally admits of a *fenk back* or depository for the refuse of the blubber immediately beneath it, which *fenk back* is sometimes provided with a *claugh* on the side next to the water for *starting* the fenks into a barge or lighter placed below. In some extensive premises, however, the fenks are deposited in a large shallow cistern or pit sunk into the earth, and made sufficiently large to contain the whole refuse of one cargo; where it remains undisturbed until the action of the sun extracts the remaining oil and brings it to the surface.

The premises likewise comprise a shed for the cooper, and sometimes a cooper's or master boiler's dwelling-house; the inhabitant of which takes the charge of all the blubber, oil, whalebone, and other articles deposited around him.

Warehouses for containing the oil after it is drawn off into casks are also used, not only for preserving it in safe custody, but for defending the casks from the rays of the sun, otherwise they are apt to pine and become leaky.

Sometimes a *steeping back* and apparatus for preparing whalebone are comprised within the same enclosure.

(633.) *Process of boiling.*—The blubber, which was

originally in the state of firm fat, is found on arrival in a warm climate to be in a great measure resolved into oil. The casks containing the blubber are conveyed, by the mechanical apparatus above-mentioned, to the top of the starting back, into which their contents are emptied or *started*, through the bungholes.

Mechanical
Processes.
Process of
boiling.

When the copper is properly cleansed, the contents of the starting back, on lifting a *claugh* at the extremity, or turning a stop-cock, fall directly into the copper, one edge of which is usually placed beneath.

In the premises of William Mellish, Esq., Shadwell Docks, London, which are the best adapted of any which Mr. Scoresby had seen, the starting back, which is about ten tons in capacity, has a false bottom full of small holes, placed a few inches above the true bottom, by which the oil is drained off, and passes through a grating and conducting pipe into an adjoining copper, and is boiled by itself, while the fenks collected by the grating are, at the same time, boiled in another copper placed equally convenient.

The copper is filled within two or three inches of the top, a little space being requisite to admit of the expansion of the oil when heated; and then a brisk fire is applied in the furnace and continued until the oil begins to boil. This effect usually takes place in less than two hours. Many of the fritters or fenks float on the surface of the oil before it is heated, but after it is boiled off, the whole, or nearly so, subsides to the bottom. From the time the copper begins to warm until it is boiled off or ceases to boil, the contents must be incessantly stirred by means of a pole, armed with a kind of broad blunt chisel, to prevent the fenks from adhering to the bottom or sides of the vessel. When once the contents of the copper boil, the fire in the furnace is immediately reduced, and shortly afterwards altogether withdrawn. Some persons allow the copper to boil an hour, others during two or three hours. The former practice is supposed to produce finer and paler oil, the latter a greater quantity. The same copper is usually boiled twice in every twenty-four hours, Sundays excepted. Supposing the copper to be filled at four in the morning, it is generally brought to boil by half-past five, and boiled off at half-past six or seven. It then stands to cool or subside until about two o'clock in the afternoon, when the *boiling* process commences. One of the backs or coolers having been prepared for the reception of oil, by putting into it a quantity of water, for the double purpose of preventing the heat of the oil from warping or rending the back, and for receiving any impurities which it may happen to hold in suspension, a wooden spout, with a large square box-like head, which head is filled with brushwood or broom that it may act as a filter, is then placed along from the *copper head* to the cooler, so as to form a communication between the two. The oil in the copper being now separated from the fenks, water, and other impurities, all of which have subsided to the bottom, is, in a great measure, run off through the pipe communicating with the cooler, and the remainder is carefully lifted in copper or tin ladles, and poured upon the broom in the spout, from whence it runs into the same cooler, at the pleasure of the *boilers*. Besides oil and fenks, the blubber of the whale likewise affords a considerable quantity of watery liquor, produced probably from the putrescence of the blood, on the surface of which some of the fenks, and all the greasy animal matter called *footje* or *footing*, float, and upon the top of these the oil. Great care,

Manufac-
tures.

therefore, is requisite on approaching these impure substances to take the oil off by means of shallow tinned iron or copper ladles, called *skimmers*, without disturbing the refuse and mixing it with the oil. There must always, however, be a small quantity towards the conclusion, which is a mixture of oil and footing; such is put into a cask or other suitable vessel by itself, and when the grosser part has thoroughly subsided, the most pure part is skimmed off, and becomes fine oil, and the impure is allowed to accumulate by itself in another vessel, where, in the end, it affords *brown oil*.

The refuse now left in the copper is *bailed* into a tunnel or spout, which conveys it into the fenk back, where it remains as long as the capacity of the vessel will admit; a portion of brown oil, which is constantly found rising to the surface, being in the mean time occasionally skimmed off.

A few years ago Mr. Scoresby, sen. instituted a process for reducing blubber into oil, by the use of steam; and a similar process has been adopted in Hull and other ports, and applied to the extraction of oil, with considerable advantage.

Product.

From a tun, or 252 gallons by measure, of blubber, there generally arise from 50 to 65 gallons of refuse, whereof the greater part is a watery fluid. The constant presence of this fluid, which boils at a much lower temperature than the oil, prevents the oil itself from boiling, which is, probably, an advantage, since, in the event of the oil being boiled, some of the finest and most inflammable parts would fly off in the form of vapour; whereas the principal part of the steam which now escapes is produced from the water. Some persons make a practice of adding a quantity of water, amounting, perhaps, to half a tun, to the contents of each copper, with the view of weakening or attenuating the viscid impurities contained in the blubber, and thus obtaining a finer oil; others consider the quantity of water already fluid in the blubber as sufficient for producing every needful effect.

Preparation
for repeat-
ing the
process.

Each day, immediately after the copper is emptied, and while it is yet hot, the men employed in the manufacture of the oil having their feet defended by strong leathern or wooden shoes descend into it, and scour it out with sand and water, until they restore the natural surface of the copper wherever it is discoloured. This serves to preserve the oil from becoming high coloured, which will always be the case when proper cleanliness is not observed.

The starting back being previously filled with blubber, its contents are again transferred into the copper, and the fire is applied as before. This is generally accomplished by four or half-past four o'clock in the afternoon. The copper again boils by half an hour after five or six, and is boiled off by seven or eight in the evening. The men employed in this service, consisting of about six persons, alternately watch in the night by couples. Those on watch commence about two in the morning to empty the copper, which done, they again fill it from the starting back, which is always made ready the night before. Thus the process goes on until the whole cargo is finished.

By means of three coolers severally capable of containing at least twice the quantity of oil produced from one boiling of blubber in the copper, each can be allowed, in turn, to stand undisturbed upwards of twenty-four hours. Thus while one is being filled, another stands to cool and settle, and the third is drawn off. If the

backs be twice the size, or four times the capacity of the copper, the oil, after being filled, may be allowed to subside during two or three days. Even two backs in number of this capacity would admit of an interval of twenty-four hours each, after being filled, before it would be necessary to begin to empty it.

Thus prepared and cooled, the oil is in a marketable state, and requires only to be transferred from the coolers into casks for the convenience of conveyance to any part of the country. Each of the coolers, it has been observed, is furnished with a stop-cock, beneath which there is a platform adapted for receiving the casks, where they are filled with ease by the introduction of a leathern tube extending from the orifice of the stop-cock into the bung-hole. At the conclusion of the process of boiling each vessel's cargo manufactured on the premises, the backs are completely emptied of their contents. To effect this, water is poured in until the lower part of the stratum of oil rises to within a few lines of the level of the stop-cock, and permits the greater part of the oil to escape: the quantity left amounts, perhaps, to half an inch or an inch in depth. To recover this oil without waste requires a little address. A deal board, in length a little exceeding the breadth of the cooler, is introduced at one end a little diagonally, and placed edgeways in its contents. The ends of the board being covered with flannel, when pressed forcibly against the two opposite sides of the cooler, prevent the oil from circulating past. The board is then advanced slowly forward towards the part of the back where the stop-cock is placed; and in its progress (the ends being kept close to the sides of the cooler, and the upper edge a little above the surface of the oil) all the oil is collected by the board, while the water has a free circulation beneath it. When the oil accumulates to the depth of the board, its further motion is suspended, until the oil thus collected is drawn off. Another similar board is afterwards introduced at the furthest extremity of the cooler, and passed forwards in the same manner, whereby the little oil which escapes the first is collected. Now the remnant which still refuses to run off by the orifice of the stop-cock being collected in a corner, is taken up by the *skimmers*, and the footing or cement which appears at the last is disposed of in the same way as the footing from the copper until the oil it contains rises to the surface and can be removed.

In most of the outports, the oil is generally deposited in casks, in which it remains until it is disposed of by the importers. In London, however, and in some concerns in Hull and other ports, the speculators in the whale fishery are provided with cisterns or tanks, wherein they can deposit their oil, and preserve it until a convenient time for selling, without being subject to the waste which usually takes place when it is put into casks. From these cisterns any quantity can be drawn off at pleasure.

The smell of oil during its extraction is undoubtedly disagreeable, but perhaps not more so than the vapour arising from any other animal substance submitted to the action of heat when in a putrid state. The prevailing opinion, however, that a whale ship must always give out the same unpleasant smell is quite erroneous. The fact is, that the fat of the whale, in its fresh state, has no offensive flavour whatever, and never becomes disagreeable until it is brought into a warm climate and becomes putrid; neither is a whale ship more unpleasant than any other trader, until after her cargo is

Mechanical
Processes.

Manufac-
tures.

Preparation
of whale-
bone.

opened on her arrival in port. Scoresby, *Arctic Regions*, vol. ii.

(634.) *Preparation of whalebone.*—Whalebone, or whale fins, as the substance is sometimes, though incorrectly, named, is found in the mouth of the common Greenland whale, to which it serves as a substitute for teeth. It forms an apparatus most admirably adapted as a filter for separating the minute animals on which the whale feeds from the sea water in which they exist.

It is a substance of a horny appearance and consistence, extremely flexible and elastic, generally of a bluish-black colour, but not unfrequently striped longitudinally with white, and exhibiting a beautiful play of colour on the surface. Internally it is of a fibrous texture, resembling hair; and the external surface consists of a smooth enamel, capable of receiving a good polish.

This substance when taken from the whale consists of laminæ, connected by what is called the *gum* in a parallel series, and ranged along each side of the mouth of the animal. The laminæ are about 300 in number in each side of the head. The length of the longest blade, which occurs near the middle of the series, is the criterion fixed on by the fishers for designating the size of the fish. The greatest length is about 15 feet; but an instance very rarely occurs of any being met with above $12\frac{1}{2}$ or 13 feet. Its greatest breadth, which is at the root end, is 10 or 12 inches, and its greatest thickness $\frac{4}{10}$ or $\frac{5}{10}$ of an inch.

The two sides or series of the whalebone are connected at the upper part of the head or crown bone of the fish, within a few inches of each other, from whence they hang downwards, diverging so far as to enclose the tongue between their extremities; the position of the blades with regard to each other resembles a frame of saws in a saw-mill; and taken altogether, they exhibit in some measure the form and position of the roof of a house. The smaller extremity and interior edge of each blade of bone, or the edge annexed to the tongue, are covered with a long fringe of hair consisting of a similar kind of substance similar to that constituting the interior of the bone.

Whalebone is generally brought from Greenland in the same state as when taken from the fish, after being divided into portable *junks* or pieces, comprising 10 or 12 laminæ in each; but, occasionally, it is subdivided into separate blades, and the gum and hair removed when at sea.

One of the first importations of whalebone into England was probably in the year 1594, when a quantity of this substance, being part of the cargo of a wrecked Biscayan ship, was picked up at Cape Breton by some English ships fitted out for the whale and morse fisheries, after the example of the Icelanders and Biscayans.

This substance has been held in so high estimation, that since the establishment of the Spitzbergen whale

fishery the British have occasionally purchased it of the Dutch at the rate of £700 *per ton*. It is calculated that at least £100,000 *per annum* were paid to the Dutch for this article about the year 1715 or 1721, when the price was £400. About the year 1763 the price in England was £500 *per ton*; but after an extensive importation of this article from New England, the price declined to £350, and subsequently as low as £50 *per ton*. Of late years the price has usually been fluctuating between £50 and £150 *per ton*. Whalebone becomes more valuable as it increases in length and thickness.

On or near the premises in which the oil is extracted the whalebone is commonly cleaned and prepared. The first operation, if not already done, consists of depriving it of the gum. It is then put into a cistern containing water, until the dirt upon its surface becomes soft. When this effect is sufficiently produced, it is taken out, piece by piece, laid on a plank placed on the ground where the operator stands, and scrubbed or scoured with sand and water, by means of a broom or a piece of cloth. It is then passed to another person who, on a plank or bench, elevated to a convenient height, scrapes the root end where the gum was attached until he produces a smooth surface; he or another workman then applies a knife or a pair of shears to the edge, and completely detaches all the fringe of hair connected with it. Another person, who is generally the superintendent of the concern, afterwards receives it, washes it in a vessel of clean water, and removes with a bit of wood the impurities out of the cavities of the root. Thus cleansed, it is exposed to the air and sun until thoroughly dry, when it is removed into a warehouse, or other place of safety and shelter.

Before it is offered for sale, it is usually scrubbed with brushes and haircloth, by which the surface receives a polish, and all dirt or dust adhering to it is removed; and, finally, it is packed in portable bundles, consisting of about a hundred weight each. The *size* bone, or such pieces as measure six feet or upwards in length, is kept separate from *under size*, the latter being usually sold at half the price of the former. Each blade being terminated with a quantity of hair, there is sometimes a difficulty in deciding whether some blades of whalebone are *size* or not. Owing to the diminished value of *under size* bone, and more particularly in consequence of the captain and some officers engaged in a fishing ship having a premium on every size fish, it becomes a matter of some importance in a doubtful case to decide this point. From a decision which has been made in a Court of Law, it is now a generally received rule, that so much of the substance terminating each blade as gives rise to two or more hairs is whalebone; though, in fact, the hair itself is actually the same substance as that of which the whalebone is composed. See the Work above quoted.

Mechanical
Processes.

Manufactures.

(635.) *Amount of Duty on Oil, Train, Spermaceti, and Blubber, with the Quantities imported, exported, and cleared for Consumption.*

Mechanical Processes.

Years.	Imported.	Exported.	Cleared for consumption.	Net Revenue.	Rates of Duty (Imperial measure.)		
					Particular kinds.	Blubber.	Train Oil.
	Imp. tons.	Imp. tons.	Imp. tons.	£.		£. s. d.	£. s. d.
1820	31,007	5,390	25,321	11,525	Greenland and Southern Fisheries.....	0 6 7	0 9 11
1821	31,275	4,052	26,921	10,487	Newfoundland and British America.....	0 16 0	1 4 0
1822	23,823	1,522	22,077	7,126	Duty on the above from Newfoundland was suspended during these years.		
					Foreign Fishing.....	26 12 0	39 18 0
					Greenland and Southern Fisheries.....	0 6 7	0 9 11
1823	30,843	1,849	28,698	11,184	Newfoundland, British America, Cape of Good Hope, and New South Wales. Duty suspended during these years.		
1824	23,863	889	22,443	7,807	Foreign Fishing.....	26 12 0	39 18 0
1825	17,748	456	16,771	2,487			
1826	22,150	582	21,568	1,070			
1827	28,040	869	26,863	5,934	Taken by crews of British ships, and imported direct from the Fishery or any British possession.....	0 1 0	0 1 0
1828	24,729	2,669	22,473	16,250	Of Foreign Fishing.....	26 12 0	26 12 0
1829	23,302	3,526	20,497	11,316			
1830	19,671	2,330	17,308	4,647			
1831	24,670	1,118	23,027	3,613			

Average Price of Oil per Tun during the above Years.

Years.	Greenland per tun.	Spermaceti per tun.	Years.	Greenland per tun.	Spermaceti per tun.	Years.	Greenland.	Spermaceti.
	£. s. d.	£. s. d.		£. s. d.	£. s. d.		£. s. d.	£. s. d.
1820	31 0 0	69 0 0	1824	18 0 0	12 0 0	1828	23 0 0	82 0 0
1821	25 10 0	72 0 0	1825	25 0 0	42 0 0	1829	26 0 0	80 0 0
1822	19 10 0	55 0 0	1826	31 0 0	52 0 0	1830	29 0 0	72 0 0
1823	27 0 0	47 0 0	1827	34 10 0	68 0 0	1831	30 10 0	74 0 0

Works employed in the Formation of artificial Substances.

(636.) In the two preceding sections we have treated, first, of the reduction of metallic ores to the purely metal form, and, secondly, of the formation of salts, acids, &c., by the natural affinities of their several components. We now propose to describe those artificial compounds produced by fusion or otherwise, which are of such extensive use in the Arts, and important to the conveniences and luxuries of civilized Society; such as bricks, pottery, porcelain, glass, &c.

Brick Works.

History of bricks.

(637.) It has been questioned which of the two sister Arts, brick-making or pottery, is the most ancient; although it is generally admitted that they both are amongst the earliest efforts of human ingenuity. Bricks are frequently mentioned in the early History of the Old Testament, as is also the potter's wheel: we should, however, be inclined, from the simple process in the one case, compared with the artificial means necessary in the other, to decide in favour of the Art of Brick-making. The walls of Babylon were unquestionably built with brick, and unburned bricks were employed in many of the antique buildings in Egypt. Several, indeed, of the Pyramids and edifices are of stone, but Pocock describes a Pyramid of unburned bricks, called "Kloube-el-Menshich," (the bricks of Menshich,) from a village near, called Menshich Dashour. It was doubtless built near the plain, on account of the bricks, which seem to be made of the earth brought by the Nile, being of a black sandy nature, with some pebbles and shells in them. It is

mixed up with chopped straw, in order to bind the clay together; as the inhabitants now make unburned bricks in Egypt and many other Eastern parts, which are used very much in their buildings. "I found," says the author, "some of these bricks $13\frac{1}{2}$ inches long, $6\frac{1}{2}$ inches broad, and 4 inches thick; and others 15 inches long, 7 inches broad, and $4\frac{3}{4}$ inches thick. I observed on the North side that the bricks were laid lengthways from North to South, but not every where in that direction; however, I particularly took notice that they were not laid so as to bind one another. It is much crumbled and ruined, but as it is I measured it, and found it to be 157 feet on the North side, and 210 feet on the West side; it is 150 feet high. By what I could judge, from the present slope of it, I concluded that it was built with five degrees, like the Pyramid of Saccara, each being about 10 feet broad and 30 deep, so that the ascent to it is easy, as the bricks are crumbled away."

Such is an account of the early unburned bricks of Egypt, and which are still in use: it does not appear, however, that brick-making in that Country is a distinct trade or occupation, the Art being practised by farmers, labourers, and tradesmen indifferently. The following account of the present practice, from No. X. of the *Architectural Magazine*, may, perhaps, be interesting to some of our readers.

"Near the bank of the Nile, or in any other place where water and rich soil may be found, one or two men go into the water, and with a rude instrument, like a carpenter's adze, they cut about two or more feet deep, six or eight feet long; the breadth is according to circumstances. After they have cut about a load of soil, they mix with it one sack full of broken straw, cut about a quarter of an inch long, (the quantity of this material

Method of making bricks in Egypt.

Manufactures.

must be proportioned to the quality of the soil,) and a certain quantity of ashes. After these materials are well mixed together, they are ready for moulding. One man takes a *barrshane* and goes to the other who is in the pit, who fills it up with the mixture; and then the first carries it to a barren place or common. When a sufficient quantity has been carried to this place, the labourers spread the cut straw over the ground where the bricks are to be made. The brick-makers then get each of them a vessel full of water, and then sit each to his work. They fill the moulds with their hands, and when each mould is full, they dip their hands into the water, and pass them over the surface of the brick to smooth it; and then taking up the mould they leave the brick on the ground to dry, and so on. When the desired quantity of bricks are made, they are left to harden in the sun; and when they become dry on the upper surface, they are turned over till they become thoroughly dry and hard enough for immediate use, or for burning."

Bricks of the Greeks and Romans.

The Greeks and Romans, although they were not unacquainted with the Art of burning bricks, yet they also employed unburned bricks, for the making of which Vitruvius gives the following directions: "They should not," he observes, "be made of stony, sandy, or gravelly loam, for such kind of earth renders them heavy; and upon being wetted with rain after being laid in the wall, they swell and dissolve, and the straw which is put in them does not adhere on account of their roughness. The earth of which they are formed should be light chalky white or red. They should be made in Spring or Autumn, as being the best time for drying; for the intense heat of Summer parches the outside before the inside is dry; which afterwards drying in the building, causes them to shrink and break. They are best when made two years before they are used, as they cannot be sufficiently dry in less time. If they are used when newly made and moist, the plaster-work which is laid on them will remain firm and stiff, but the bricks shrink, and, consequently, not preserving the same height with the incrustation, it is by such contraction loosened and separated. At Utica, therefore, the law allowed no bricks to be used before they had lain to dry five years."

Proper earth for bricks.

The earth proper for making bricks is a clayey loam, neither abounding too much with sand, which renders them brittle, nor with too large a portion of argillaceous matter, which causes them to shrink and crack in drying. As the earth before it is wrought is generally brittle, and full of extraneous matter, it should be dug two or three years before it is used, so that, by being exposed to the action of the atmosphere, it may be sufficiently mellowed and pulverized, and thus facilitate the operation of tempering. At any rate it should always have one Winter's frost; but the longer it lies exposed, and the more it is turned over and wrought with the spade, the better will be the bricks.

Tempering the clay.

The tempering of the clay was formerly, and is still, in some places, performed by the treading of men or oxen, but it is now most commonly effected by means of a clay or pug-mill, consisting of a large vertical cone, having strong knives with a spiral arrangement and inclination fixed on its internal surface. Passing through the centre, and terminating in a pivot at the bottom, is a strong perpendicular shaft with similar radiating knives, so that the knives, by the revolution of the shaft, cut, separate, and mix the clay, till it is reduced to a homogeneous paste, which passes through an orifice at the bottom into a receiver placed for that purpose.

The clay is then taken from the receiver to the moulder's bench, and is, either by a lad or a woman, cut into pieces somewhat larger than the mould, and passed on to the moulder, who works it into a mould, previously dipped in sand, and strikes off the superfluous parts with a flat smooth piece of wood. In this Country, the mould used is about 10 inches in length and 5 inches in breadth, and the bricks when burned are about 9 inches long, $4\frac{1}{2}$ inches broad, and $2\frac{1}{2}$ inches thick. The degree of shrinking, however, is various, according to the temper and purity of the clay, and the degree of heat attained in the burning. A handy moulder is calculated to mould from 5000 to 7000 per day.

Mechanical Processes. Moulding.

From the moulder's bench the bricks are carried to the stack, and arranged somewhat diagonally, one above the other, and two edgewise across, with a passage between the heads of each for the admission of air, till they are eight bricks in height. They are then left to dry. The time they take before they require shifting depends entirely upon the weather, which, when fine, will be but a few days; they are then turned and reset wider apart, and in six or eight days are ready for the clamp or kiln.

(638.) *Burning the bricks*, which is the next operation, is performed either in a kiln or in a clamp. In the former the bricks being set, and the kiln covered with pieces of the same, a gentle fire of wood is made to dry them; and this is kept up until they are pretty dry, which is known by the smoke turning from a whitish to a thin black smoke. Wood is then no longer used, but in its stead brush, furze, straw, brake, or fern faggots are employed. Having first closed up the mouth of the kiln with a thin log, (or pieces of brick piled upon one another, and closed with wet brick earth instead of mortar,) more faggots are used till the kiln and its arches look white, and the fire appears at the top, upon which the latter is slackened for an hour, and left to cool by degrees. Thus the workmen continue alternately heating and slackening till the bricks be thoroughly burned, which is usually effected in forty-eight hours.

Burning.

Clamps are generally employed about London, which are built of the bricks themselves, after the manner of arches in kilns, with a vacancy between each of a brick's breadth, for the fire to play through; but with this difference, that, instead of arching, the flues are gathered over by making the bricks project over one another. The place for the fuel is carried up straight on both sides till about three feet high; it is then nearly filled with wood, and over that a stratum of sea coal, and then the earth; sea coal is also strewed between every row of bricks in the clamp; lastly, the wood is kindled which communicates with the coals, and when all is exhausted the bricks are considered to be sufficiently burned.

The proper burning of bricks is a matter of considerable difficulty, and requires an experienced workman; as it is necessary to maintain an equal heat throughout the whole mass, neither too little, which would leave the bricks weak and crumbly, nor too great, which would cause them to run together into a vitrified slag. The operation is for this reason much better performed in kilns than in clamps, as the fire can be kept up and regulated at discretion; while in clamps, as the whole of the fuel must be put in at once, the manufacturer is always tempted to use too little, and the outside bricks are necessarily under-burned. These are called *samel* bricks, and are sold at an inferior price.

Manufac-
tures.

The different kinds of bricks made in this Country are principally *place bricks*, *grey* and *red stocks*, *marle facing bricks*, and *cutting bricks*. The *place bricks* and *stocks* are used in common walling. The *marles* are made in the neighbourhood of London, and used in the outside of buildings; these are very beautiful bricks, of a fine yellow colour, hard, and well burned, and in every respect superior to the *stocks*. The finest kind of *marle* and *red bricks* are called *cutting bricks*; they are used in the arches over windows and doors, being rubbed to a centre and gauged to a height. There is also a fine kind of white bricks made near Ipswich, which are used for facing, and sometimes brought to London for that purpose. The *Windsor bricks* or *fire-bricks*, which are made at Hedgerley, a village near Windsor, are red bricks, containing a very large proportion of sand; these are used for coating furnaces, and lining the ovens of glass-houses, where they stand the utmost fury of the fire. *Dutch clinkers* are also imported; these are long narrow bricks of a brimstone colour, very hard and well burned; they are frequently warped, and almost always vitrified. The use of them is for paving yards and stables.

Duty on
bricks.

(639.) *Duty on bricks*.—By 17 Geo. III. c. 42. all bricks made for sale shall, when burned, be not less than $8\frac{1}{2}$ inches long, $2\frac{1}{2}$ thick, and 4 inches wide.

By 43 George III. c. 69. (consolidating the Excise duties,) passed July 4, 1803, every thousand of bricks made in Great Britain, not exceeding 10 inches long, 3 inches thick, and 5 inches wide, are liable to a duty of five shillings, and exceeding the aforesaid dimensions to ten shillings; and every thousand of bricks made in Great Britain, and smoothed and polished on one or more sides, not exceeding the superficial dimensions of 10 inches long by 5 inches wide, are subject to a duty of twelve shillings, and if such bricks exceed these dimensions, to the duty on paving tiles. The said duties are to be paid by the makers. An additional duty of tenpence per thousand was imposed on bricks and tiles in the Ways and Means for the year 1805.

The policy of the tax on bricks has always been much questioned, not merely as regards the amount, but as placing the maker under inconvenient restrictions. On this head Mr. Bakewell, in his Treatise on brick-making, observes: by the 17 Geo. III. c. 42. bricks made for sale in England must be $8\frac{1}{2}$ inches long, $2\frac{1}{2}$ inches thick, and 4 wide; the size of the sieves for sifting coal ashes to mix with the clay must not exceed a quarter of an inch between the meshes; the reader, however, will see most clearly the onerous nature of the laws governing this simple branch of rural employment in the following paragraph.

Notice must be given of the intention to begin *making* under the penalty of £100; the size, the form, and, it may be said, the quality of the article, is prescribed, and the size of the sieve is fixed. The articles are chargeable with the duty, (subject to an allowance of ten in the one hundred for waste,) directly as they come from the mould. From the nature of the manufacture, this is, however, insufficient, and the same raw material may have to pay the duty several successive times; for as all the processes take place in the open air, the article is liable to be injured, or even destroyed, by heat, by cold, or by rain; and when a batch has successfully escaped the elements, there is still the ordeal of the kiln. Thus when the bricks on leaving the mould are *set up*, they may be destroyed by frost in a single night. After reworking and repaving they may be washed away, or

otherwise damaged, by a storm or land flood. If the material, or any part of it, is again reworked, the duty is again levied, and the bricks are placed in *clamp*; where they may, from accident, turn out *shaky*, or be altogether spoiled. For natural risks, the consumers of a manufacture must of course pay; but in the present case the premium of insurance is very greatly raised by the tax, while the risk itself is very greatly increased by the regulations. For instance, when the bricks are once *set up*, there they must remain till the officer has brought them to charge, or, what is virtually the same, has given permission to remove them, although their non-removal should subject them to be injured or destroyed. Every spot on which they are placed during the process of a manufacture must be entered. If from accident, carelessness, or design, they are put in an unentered place, the maker is subjected to the penalty of £50. After all, the duty only yields £365,000, and from which there is to be deducted the expense of the collection. This is very considerable, for brick fields are scattered all over the country, and frequently established for temporary purposes; as when houses are to be erected in a remote neighbourhood, or when brick earth is found upon the intended site, and the builder turns brick-maker, probably at a considerable distance from any Excise station.

Mechanical
Processes.

(640.) *The following Table shows the Number of Bricks made, and the Revenue arising thereby, from 1820 to 1831.*

Years.	Number of bricks paying duty.	Number of tiles paying duty.	Revenue.
			£.
1820	996,998,199	83,395,113	319,619
1821	978,655,642	81,926,622	310,668
1822	992,979,626	73,947,261	339,077
1823	1,265,612,759	82,744,380	407,408
1824	1,493,425,655	88,439,962	479,097
1825	1,991,405,278	98,063,534	629,372
1826	1,381,014,528	99,856,367	449,587
1827	1,123,709,966	91,823,189	368,789
1828	1,103,626,961	79,853,174	356,868
1829	1,134,834,993	77,561,516	363,430
1830	1,112,230,188	71,252,474	348,411
1831	1,124,180,127	69,521,188	365,237

Pottery.

(641.) The potter's Art seems to have been nearly coeval with civilized Society. It was undoubtedly in the earliest stages of a very inferior quality; but the Egyptians, Greeks, and Romans possessed it in a high state of perfection, and the Chinese have been celebrated for their ware from the earliest periods of their History. Common pottery has also been known and practised for many Ages by all European nations; but it was only at the commencement of the last century that it began to assume a scientific character, first in Dresden, then in Holland, France, Germany, and England; and in this Country during the last half century it has made a progress so extraordinary as at this day to rival, if not to surpass the works of any nation, not excepting the Chinese. Our limits will not admit of our following out the details of its history, because we are desirous

Manufactures. of entering at as great a length as possible into a description of interesting particulars connected with its manufacture, with which we have been kindly furnished by a gentleman resident in the Potteries, who has very carefully attended to every manipulation connected with the Art.

Terms defined.—The manufacture of ductile earths into vessels of capacity for the various purposes of the table and the toilet, also into ornamental figures, vases, busts, and bas reliefs, enhanced in value by their elegance and durability, is technically named *potting*; the suite of erections for carrying forward the processes and operations, a *pottery*; and the manufactured articles according to their nature and quality, the finest and semi-transparent, *porcelain* or china, the completely opaque but fine, *earthen ware*, *flint ware*, *queen's ware*, *delft ware*, &c., and the coarser kinds, *stone ware* and *pottery*.

Porcelain.

Different descriptions of ware

(642.) The finest branch of this manufacture includes two kinds, from their components named *hard* and *soft*. The former constantly, the other partially, when fractured, exhibits a texture and grain compact, is hard, firm, dense, durable, and semi-vitreous; when struck by a hard body is sonorous; in appearance is white or milk colour, semi-transparent, and intermediate between the closeness of glass and the obvious porosity of the best flint pottery; is covered with a transparent glaze, smooth, fine, clear, white, and not affected by acids or alkalis; and sustains, without failing, sudden alternations of temperature. These are essential properties.

Pottery of the best kind.—Flint ware or queen's ware, delft ware, (and the word is also applied to coarse common ware,) for the table, the toilet, and various domestic purposes, has coarser texture and grain than porcelain; is not semi-transparent, nor vitreous, though firm, hard, sonorous, durable, and covered with a rich vitreous glaze, not affected by acids, alkalis, or sudden alternations of temperature. Also including that very important branch,

Chemical utensils, such as alembics, crucibles, dishes, retorts, tubes, and many other implements indispensable in the laboratory.

The manufacturer's chief object of attention is, to compound his materials with so strict a regard to chemical science, as will ensure to his ware certain essential and indispensable qualities.

Hard porcelain.—With a body very dense and durable, fracture vitreous, white, semi-transparent, sonorous when struck by a hard body, and with a clear indestructible glaze, smooth to the touch, beautifully fine, appearing soft like velvet, rather than lustrous or glossy like satin, resisting the action of acids and alkalis, and uninjured by alternations of temperature.

Soft porcelain.—Body less dense, yet sonorous, granular, and very fine porous fracture, harder and less brittle than glass, white, semi-transparent, moderately hard glaze, and will bear considerable alternations of temperature.

Flint ware.—Body in texture and grain moderately dense, porous fracture, sonorous when struck, with glaze fine, clear, free from specks, transparent to show the ornamental designs made on the biscuit, not affected by acids, alkalis, or sudden alternations of temperature.

The Dresden porcelain, equally fixed and infusible as

the Japanese, is in some qualities decidedly superior; it is firm and compact, and will sustain without injury sudden change of temperature; its fracture is not granular but uniform, and similar to white enamel. Its fusible components are from the tarso of the river Po; and its infusible is the clay from Aue, near Schneeberg; which Rose states to contain silica 52, alumine 47, iron 0.33. But these are not chemically equivalent, and some error perhaps exists in the analysis. When these substances are combined, in proportions not here ascertained, the felspar gravel, by its fusibility, promotes the density, smoothness, and superior lustre, while the clay gives to it its firm solidity and beautiful white appearance; and together there is regular contraction during the process of baking.

The porcelain of Berlin is formed of the tarso, and clay from the valley of Gatach, above Haussach, in Wirtemberg; those of Vienna, Frankendal, and other places in Germany, of the tarso, and clay from near Passau; but there is such variation in the proportion, or the process, or both, as to cause considerable difference, as well from the Dresden, as from each other. And equal difference exists between those of Villaroy and Orleans, of Naples and Florence (the latter resembling the best qualities of the Oriental); these use the felspar and clay from Alençon, and St. Yrieux la Perche, near Limoges, and some from near Bayonne.

The Sevres porcelain excels all the others manufactured in France; (although great improvement has been made therein;) in its fracture it is more like very fine lump sugar than a vitrified substance, has all the other properties of true porcelain, and is covered with a glaze colourless and transparent. The proper components are, for the body, felspar 67, clay 33; and for the glaze, felspar 85, potass 15. Other numbers and substances have been given; as clay 66, felspar 15, sulphate of lime 9, whiting 6, ground pieces of ware 10; glaze, melting spar 75, sulphate of lime 12, and ground ware 12; but we believe those assigned above are correct. The following comparison will probably supply useful information as well as gratify curiosity.

	English.	Sevres.	Dresden.	Berlin.	Nankin.
Silica.....	0.770	0.696	0.602	0.590	0.660
Alumine...	0.086	0.250	0.320	0.340	0.180
Potass....	..	0.020	0.020	0.010	0.120
Soda.....	..	..	..	..	..
Lime.....	0.012	0.024	0.018	0.008	0.040
Magnesia..	0.050	..	..	0.027	..
Water....	0.050	0.008	0.040	0.012	..
	0.968	0.998	1.000	0.987	1.000

The *stone china*, in much demand for table and toilet services, is a very thick, strong, semi-transparent ware, coarse in texture, vitrescent, and granular in fracture, and durable, but with a glaze very soft compared with the Oriental porcelain it is intended to imitate. An addition of slag from the iron-smelting furnaces produces the kind called *patent ironstone china*.

The appellation of *dry bodies* is given to unglazed ware, of different colours, which is formed into elegant and valuable articles; several are so compact and highly vitrified as neither to require, nor indeed to receive a glaze; their surface presents minute pores from the fusion of the components, and their beauty is improved by absence of the vitreous coating, which prevents the sharpness of the fine lines appearing prominent; and however well adapted for utility, can never equal the

Mechanical Processes.

Manufac-
tures.

elegance of a polished surface. To this class belong the wine-coolers or *alcarazas*, formed of a size sufficiently large to admit a bottle within the cylindrical part, and ornamented on the outside. Butter coolers are smaller in size. The components are only partially baked, and yet sufficiently adhesive to sustain without injury the constant oozing of the water through them on all sides. After being filled with water till the pores are saturated, the bottle is put in, and the action of the surrounding air on the water, as it evaporates outside, induces such a reduction of temperature as affects completely the contents of the bottle.

The *chemical utensils* body is adapted to sustain, uninjured, the action of different powerful agents; and very recently the younger Josiah Wedgwood, of Etruria, has greatly improved this important article of the Chemist's laboratory. Certainly no compound wherein silica is present can completely resist the action of all chemical preparations; but as far as possible this should be counteracted by suitable components. All chemical action being in proportion to the exposed surfaces of the opposing substances, the greater the comminution of the silica in the vessels used for such fluents, the less opportunity will there be for destructive effect. How this great comminution is accomplished, will presently be mentioned.

Those chemical utensils which are intended to be subjected to the action of heat should be refractory at any temperature easily and usually applied; should bear saline and other fluxes in fusion without being permeated or injured thereby, and should neither crack nor fly by sudden application of heat, nor yet of cold when heated. How these valuable properties are secured to the ware is indispensably needful to be mentioned. The compound ascertained to be most refractory has a fourth part of baked ware again ground very fine, mixed with clays that are not spiced with lime, as this would promote the fusibility of the silica. It is probable that the practice has originated from a remark of the younger Pliny; (*Nat. Hist.* lib. xxxv. c. 12.) "Strong mortar or cement was made by the broken sherds of potters' vessels ground into powder and tempered with lime; which being firmer and lasting longer was called *signina*." The intermixture of ground pitchers is constantly practised in the Sevres manufactory; and when these are not at hand, an artificial substitute is prepared and ground. The French also grind up their old Normandy butter pots to mix with aluminous schist, and bake at extremely high heat for their crucibles. And our seggar-makers adopt the principle in their productions; as likewise do the makers of the glass-house crucibles, though extremely strong, and for this reason: unless the components will equally contract and expand together on change of temperature, and unless there be provision made in the compound for any slight excess of a refractory or of a fusible component, cracking will ensue; as has been proved innumerable times with even Wedgwood's best vessels, though slowly and gradually raised and coated with fire-lute, sand and clay, horse dung and tow, Windsor loam, and Cornish clay slip; therefore, when the fresh materials are mixed with the old in a state of impalpable powder, while the vessel will be compact and firm, little liable to be injured by acids or alkalis, there would be provision for the reaction of the fresh components on any rise of temperature. Crucibles for the fusion of metals only are made by mixing very intimately with the clay, carburet of iron, (black

lead,) which at all temperatures being infusible, and devoid of tendency to combine with the clay which protects it from the action of the atmosphere, is incombustible, and less than any other compound affected by the sudden changes of temperature; yet without retaining, as do the sides of other crucibles, any portion of the fused substances. Hessian crucibles, which are firm, compact, and at high heats retentive of saline fluxes, are formed by pressing with great force into an iron mould, a just moistened mixture of felspar, refractory clay three parts, and one part of coarse washed sand.

The *flint ware*, (technically named *earthen ware* and *pottery*,) like all the preceding, is a compound of different earths, well baked first, and then covered with a fusible white glaze or enamel. The kinds of flint ware differ much, according to the qualities and proportions of the earths used as components, in their firmness, and sustaining sudden changes of temperature without breaking; some of the best being easily affected by a brisk fire, and others, common and rather coarse, often remaining uninjured by it. They differ equally in the beauty and excellence of their glaze or enamel, figures, and methods of decoration.

The *Delft ware*, so named from the town in Holland at which it is made, first suggested the Staffordshire white stone ware, and flint ware followed. The delft is made of a compound of earths, clay alone not being proper, neither will pure clay answer. When the clay has excess of alumine, the workman calls it *too fat*; and vessels made of it, even though exceedingly thick, would require a long time to dry, lose their form, and crack by the natural escape of the water. To take away this fatness, still to preserve the mass sufficiently ductile and adhesive to bear the requisite manipulations of the thrower, turner, and presser, a quantity of sand or marl is added; the silica acidulates the excess of the alumine, and counteracts the usual tendency of the clay to shrink or contract, which cracks the vessel; the ware is rendered less compact, the water escapes without the ware being injured by the drying; while a compound of blue clay with marl only is not firm and solid for the purpose required, and the enamel scales off, as in the *overflinting* of flint ware, unless it is baked at a very high temperature; whereas the usual practice is to bake it slightly to prevent its sinking on applying the enamel; but when two or more clays are partially mixed, and sand or marl is added, the first baking supplies a proper ground for the enamel, which appears white and more glossy than on the other bodies. The components of the glaze, according to M. Bosc d'Antic, are for the common delft ware, calc of lead 46, calc of tin 6, fine sand 40, sea salt 8; for the best 38, 10, 40, 12, respectively.

Clay, in the manufacture, is the name of every different compound of earths, and *body* is that of the mass in reference to its properties, and as distinguished from its *glaze* covering. As each manufacturer endeavours to give distinction to his ware by some supposed excellence in mixing the several components, numerous different proportions are given in recipes, and consequently the relative qualities result from some factitious circumstances. Of the porcelains, some are white, beautifully semi-transparent, and smooth-glazed, yet will scarcely bear the manipulations, are easily fused in baking, light in weight, crack on rise of temperature, and the glaze so soft as to wear off, or become dull and rough; and others are greyish in colour, sustain

Manufactures.

Recipes for bodies and glazes.

the working, bake compact and dense at a very high heat, and are not injured by customary changes of temperature. The body has definite quantities of the Middleton Hill felspar and china clay of Cornwall; and the glaze likewise of fine felspar and alkali.

(643.) The following recipes produce *bodies* and *glazes*

differing in excellence in consequence of some factitious circumstances; they are, however, of general utility; and the results will be satisfactory when the materials are compounded in the manner directed. The Cornish stone is being rapidly superseded by the Middleton Hill kaolin for body, and the petuntse for glaze.

Mechanical Processes.

Bodies.	Cream colour.												Chalky.						Blue Printing.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	11	12
Blue clay	24	30	30	66	36	30	24	24	24	20	30	24	24	30	26	28	30	40	30	32	34	34	40	26	32	40	36	50	54	56
Black ditto	16	18	16	..	16	20	20	24	20	20	12	16	12	10	..	10	14	..	15	16	..	12	10	14	12	10	10	..	..	..
Brown ditto	12	8	16	..	16	20	10	24	12	20	16	12	..	10	10	..	..	..	15	10	10	10	8	10	..	10	4	..	..	..
Cracking ditto	12	..	8	..	8	10	10	..	8	..	6	12	6	..	..	..	..	..	..	10	4	..	..	8	..	..	2	..	..	..
China ditto	16	24	10	17	..	..	16	8	14	12	16	16	24	20	26	28	24	20	20	16	20	16	18	20	24	16	20	24	14	20
Flint	16	16	12	17	20	20	16	16	16	20	16	16	30	26	32	30	28	34	15	16	20	20	18	24	20	20	24	18	16	24
Kaolin	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5	10	6	..	..	..	..	..	..	..	16	10
Cornish stone	4	4	8	..	4	..	4	4	6	8	4	4	4	4	6	4	4	6	..	..	..	4	6	6	4	4	6	6	..	..
Glazes.																														
Cornish stone	23	30	25	30	26	27	22	36	30	26	34	40	32	..	..	..	..	..	..	..	..	26	..	..	30	..	..	..	..	..
White lead	48	30	50	56	50	48	60	36	38	50	50	50	48	..	..	..	..	..	..	..	..	50	..	..	40	..	..	..	..	..
Flint	14	20	14	14	11	15	18	12	16	12	12	10	20	..	..	..	..	..	..	..	..	14	..	..	12	..	..	..	..	..
Flint glass	15	20	11	..	13	10	..	16	16	12	4	..	..	..	..	..	..	..	..	..	..	10	..	..	18	..	..	..	..	..

Glaze for No. 8, 9, and 10, *Blue Printing*. *Fritt*.—Glass 69, litharge 18, nitre 8, arsenic 4, cobalt blue 1.

Or, fritt 6, flint 14, Cornish stone 26, white lead 54.

Glaze for enamelling.—*Fritt* 5, flint 15, Cornish stone 25, litharge 55.

Glaze for 5 and 6, B. P. *Fritt*.—Glass 70, litharge 22, nitre 4, arsenic 4, blue calc 1.

Glaze for cream colour.—Glass 50, common glass 20, fritt 30. Grind well together.

Glaze for coloured.—*Fritt* 18, flint 10, stone 25, white lead 48.

Glaze for mocha.—*Fritt* 13, flint 11, stone 26, litharge 50.

Glaze for printing.—*Fritt* 12, flint 20, stone 23, litharge 45.

Glazes for 1, 2, 3, 11, 12, B. P.—Petuntse 66, barytes 12, boracic acid 18, common salt 3, nitre 1.

Or, petuntse 75, barytes 12, boracic acid 8, common salt 4, nitre 1.

Or, petuntse 65, barytes 14, boracic acid 18, common salt 1, nitre 2.

Or, petuntse 56, barytes 12, boracic acid 15, common salt 9, potass 8.

Or, petuntse 57, barytes 12, boracic acid 15, common salt 8, potass 8.

When the cream-coloured glaze has excess of borax, it is transparent and greenish-yellow; and the borax is of great power as a flux of the earths and metallic oxides; but being soluble in water, and efflorescent in air, defective chemical combination will present opportunity for *crazing* equally with imperfect combination of the components of the glaze with those of the body, or their unequal degree of fusibility, or insufficient baking, or excess of uncombined alkali, or exposure while hot in the oven to the current of air. Instead of borax, in coloured glazes, nitre is substituted, and, without affecting their fusibility, it promotes the high oxidation of the metals, and thereby improves the lustre of the colours. The nitre is decomposed by silica, alumine, and barytes, com-

binning with its base in the high heat while baking the glaze; but it is injurious in fluxes for blue, green, pink, or purple colours.

The tendencies and action of boracic acid are sluggish compared with those of other acids; it melts below red heat, yet this is requisite that it may flow freely; it is more refractory than borax, and when cool is hard, vitreous, and moderately transparent. Its rejection of alumine would, however, preclude its application in the manufacture, did not the very high heat of the oven particularly facilitate the fusion of the silica into a vitreous solid mass not alterable by the atmosphere, and render liquid the other earths present during the fusion; it also disperses all acids except the phosphoric, remaining unvolatilized by any heat usually applied in baking the glaze.

In lead glazes, arsenic has been used as a component of the fritt, under the idea that it rendered the glaze *whiter*; but the fact must not be overlooked, that from its tendency ever to precipitate lead in its combinations, *crazing* will readily ensue. The green tint is often improved by it, when sulphate of copper is employed. It has also another use, (and some persons substitute either manganese, or nitre,) to counteract the yellowish tinge often caused by the carbon of the fuel, without producing opacity of the glaze; the volatilization of the arsenic, by dissipating the gas of the carbonic acid, leaves the glaze not cloudy, but white, clear, or transparent.

Many of the less valuable kinds of flint ware are coloured by some additions to the materials for the glaze, forming what are called *dips*, *smears*, and *washes*. *Black dips*.—Blue clay 46 or 84, ochre 46 or 12, manganese 8 or 4. Mix in water, and pass through 12 lawn.

Black shining glaze.—Flinted slip 60, red lead 40 to 86, add manganese 14; or, flint 10, white lead 66, manganese 20, iron scales or sparks 4. Grind.

Brown dips.—Ochre 13, manganese 7, turner's shavings in slip 24 ounces, to pint 80.

Manufactures.

Or, calcined nickel 8, ochre 23, brick clay 23, Bradwell wood clay 23, brown clay 23.
 (Mingled.)—Or, shavings slip 75, calcined iron sparks 25, pass through 12 lawn, or yellow clay 97, zaffres 3.
 (Dark.)—Or, brown dip 80 or 48, slate clay (iron stone) 20 or 6, manganese 46.
 Or, brown dip 56, flinted slip 34, ochre 8, manganese 2, (or 4,) and Spanish brown 4, for porcelain.
 Red dip.—Brick clay 60, Bradwell wood clay 40.
 Brown glazes.—No. 1, raw glaze 33, No. 5, fritt glaze 67. For necks of jugs 67, and 33, (reversed.)
 Or, best flinted slip 33, flint 5, red lead 62. (For black, add manganese 2.)
 Blue dips.—Blue clay 28, petuntse 50, calcined gypsum 20, blue calc 2.
 Or, blue clay 26, Cornish stone 50, calcined gypsum 20, blue calc 4.
 Or, blue clay 38, petuntse 54, calcined gypsum 0, blue calc 8.
 Or, brown clay 23, China clay 15, flint 27, Cornish stone 27, blue calc 8.
 Grey dips.—Best flinted slip 75, flint 15, emery 6, manganese 4. Grind well.
 Or, best shavings slip 24 ounces to pint, 94, zaffres 6.
 Green dips.—Best flinted slip 96, copper calc 1, zaffres 3, (for sponge,) cane dip 96, zaffres 4.
 Or, calcined blue clay 75, zaffres 25, calc 20, best flinted slip 80.
 Or, (dark) stone body slip 94, zaffres 6, (olive,) black marl slip 92, zaffres 8.

Green glazes. Fritt.—Lead 54, flint 27, blue clay 9, copper calc 9, blue calc 1, raw glaze (2) 85, fritt 15.
 Or, Fritt.—Lead 33, copper calc 28, flint glass 17, flint 22, printing glaze (4) 80, fritt 20.
 Or, (for desserts) glaze 76, fritt 24; (for edging) glaze 60, fritt 40.
 Or, glaze (7) 1 gallon, biscuit yellow 12 pound, copper calc 8 ounces.
 Orange dip.—Brown dip 50, black marl slip 50. Cane dip.—Orange dip 50, best slip 50.
 Yellow glazes.—Raw cream colour glaze (2) 72, litharge 14, base yellow 14, or B. P. glaze (4) 80, biscuit yellow 20.
 Smears.—In hot water dissolve pearl ashes 60, nitre 16, rock salt 24, glaze (2) 80, solution 20.
 Or, in hot water dissolve pearl ashes 45, nitre 22, rock salt 33, glaze 86, solution 14.
 Or, in hot water dissolve pearl ashes 9, nitre 32, rock salt 59. For printing glazes.
 Or, in hot water dissolve pearl ashes 48, nitre 18, rock salt 34. For printing glazes.
 Or, in hot water dissolve pearl ashes 42, nitre 4, rock salt 27, soda 27. For printing glazes.
 Glaze for brown lined ware.—White lead 50, Cornish stone 40, flint 8, glass 1, borax 1.
 Blue and green. Edged.—Litharge 44, Cornish stone 24, flint 12, glass 12, fritt 8.

Mechanical Processes.

Bodies.	Porcelain, Bone.									Stone.					Felspar.								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	1	2	3	4	5	6	7	8	9
Bone, calcined	40	46	60	50	40	28	25	29	46	..	..	..	..	36	..	..	..	..	..	..	..	..	..
Cornish stone.	20	18	16	8	24	40	25	40	28	48	..	50	..	12	..	..	..	..	..	..	..	..	..
China clay ...	30	32	20	35	20	7	16	8	20	27	30	38	30	25	30	30	22	30	30	2	20	20	25
Blue clay ...	4	4	4	4	6	20	25	18	6	18	14	5	20	12	10	10	28	6	10	1	10	10	10
Flint.	6	..	..	3	10	5	9	5	..	7	8	7	15	15	5	10	30	14	20	2	20	16	15
Kaolin.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Glazes Raw.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Cornish stone.	25	35	20	25	30	40	15	30	32	..	40	..	40	28	..	..	..	..	..	..	..	..	..
Red lead	30	30	23	45	20	18	44	30	40	..	..	..	..	16	..	..	..	..	..	..	..	..	..
Borax.	16	3	19	..	8	..	6	8	..	..	22	..	11	..	..	..	..	..	..	..	..	..	..
Flint.	12	14	16	14	14	12	15	20	8	..	28	..	11	16	..	..	..	..	..	..	..	..	..
Flint glass. .	12	18	12	12	22	30	20	12	20	..	..	..	..	27	24	..	..	..	..	..	..	..	..
Potass.	..	..	..	..	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Soda.	5	..	6	4	..	..	..	..	..	..	20	..	..	..	..	..	..	..	..	..	..	..	..
Nitre.	..	..	..	4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Barytes.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Petuntse.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Fritt bodies.

(644.) Fritt Bodies. Porcelain.
 Fritt.—Cornish stone 40, bone ash 40, flint glass 20.
 Body: fritt 80, blue clay 20.
 Fritt.—Cornish stone 50, bone ash 50. Body: fritt 95, blue clay 20, flint 5.
 Fritt.—Cornish stone 40, bone ash 29, cullett 22, borax 9. Body: fritt 48, China clay 38, British clay 14.
 Fritt.—Cornish stone 22, flint 28, cullett 28, white lead 12, salt 3, borax 6, British calc 1. Body: fritt 40, China clay 48, blue clay 12.
 Fritt.—Kaolin 75, borax 20, sal ammoniac 5. Body: fritt 50, China clay 30, blue clay 10, flint 10.

Fritt.—Kaolin 60, borax 25, sal ammoniac 10, nitre 5.
 Body: fritt 45, China clay 40, flint 5, blue clay 5.
 Fritt Glazes, Porcelain, or best Flint, Blue Printing, and Enamel.
 Fritt.—Cornish stone 44, flint glass 30, flint 18, borax 4, nitre 4. Glaze for porcelain. (2) Body: fritt 44, cream-colour glaze (2) 56. Blue printing: fritt 78, lead 22, or 70 and 30.
 Fritt.—Flint glass 75, red lead 15, arsenic 3, nitre 7. Glaze: fritt 80, white lead 20.
 Fritt.—Cornish stone 31, flint glass 38, borax 31. Glaze: fritt 80, white lead 20.

Manufactures. *Fritt.*—Cornish stone 80, soda 20. *Glaze:* fritt 40, Cornish stone 20, flint 15, white lead 25.

Fritt.—Flint glass 76, red lead 7, potass 7, arsenic 4, nitre 6, also flint glass 47, potass 53. Mix fritts. *Glaze:* fritt 80, lead 20.

Fritt.—Cornish stone 24 and 13, flint glass 48 and 73, red lead 20 and 9, nitre 1½ and 4, flint 5, arsenic ½. *Glaze:* Cornish stone 30, fritt 36, flint glass 26, white lead 5, potass 3.

Fritt.—Petuntse 70, carbonate barytes 7, carbonate lime 10, boracic acid 12. *Glaze* for printing: fritt 64,

or boracic acid 26, nitre 5, potass 5; for enamelling, fritt 58 or 62, boracic acid 39 or 38, and nitre 3 or 0. **Mechanical Processes.**

Fritt.—Petuntse 60, calcined borax 34, nitre 4, soda 2. *Glaze:* fritt 60, borax 40.

Fritt.—Petuntse 60, borax 24, carbonate barytes 6, nitre 3, potass 3, salt 4. *Glaze:* fritt 62, boracic acid 32, nitre 6.

Fritt.—Petuntse 52, borax 36, China clay 3, nitre 7, soda 2. *Glaze:* boracic acid 40, fritt 60.

Dry Bodies.	Jasper.				Pearl.				Stone.				Chemical Utensils				Cane.			Drab.			Black.			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4										
Kaolin	18	..	32	..	30	..	..	40	50	..	..	30	40	30	..	..	18	..	..	25	..	..	..	10	..	8
Cornish stone....	..	33	..	20	..	60	54	..	..	40	46	..	..	..	40	33	..	24	32	..	45	40	..	..	6	..
China clay	7	17	30	14	32	22	36	12	25	10	12	16	30	30	20	20	..	..	..	6	..	10	..	..	4	..
Blue clay	40	17	28	18	14	14	4	44	25	30	24	54	30	40	25	25	18	16	24	46	27	16	37	36	40	36
Marl.....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	5	11	64	60	44	26	20	40	..	14	..	16
Flint	..	6	..	12	10	..	..	..	..	5	12	..	..	..	10	11	..	..	..	..	..	..	..	..	..	..
Flint glass	..	..	..	8	14	4	6	4	..	15	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Barytes carbonate	35	27	10	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Manganese.....	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	2	4	5	4	8	6	..
Calcined ochre...	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	48	36	44	30

Fritt jasper bodies.—The materials to be ground together in slip.

Fritt.—Cornish stone 40, 50, 35, 40, gypsum 30, 50, 26, 40, flint glass 24, 24, 12, 12, flint 0, 16, 6, 6. *Body:* barytes sulphate 32, 32, 30, 34, China clay 18, 37, 30, 30, blue clay 18, 13, 10, 6, fritt 32, 50, 32, 30.

Fritt pearl bodies.—Grind all together in slip.

Fritt.—Flint glass 76, 62, 80, 70, red lead 22, 20, 20, 24, borax 2, 4, 0, 0, nitre 0, 8, 0, 6, flint 0, 6, 0, 0, *Body:* fritt 12, 16, 12, 20, 16, blue clay 38, 24, 28, 26, 30, Cornish stone 50, 46, 60, 0, 54, kaolin 0, 0, 0, 54, 0.

Porous bodies.—Marl 88, 84, 84, 86, blue clay 9, 10, 8, 8, flint 3, 6, 8, 6.

Cottage brown.—Bradwell clay 80, 60, 70, brick clay 14, 24, 20, flint 6, 16, 10.

Best red body.—Bradwell clay 25, 30, 40, brick clay 50, 30, 40, flint 20, 22, 10, blue clay 5, 18, 10.

The baking process will give a varied tint, from the place in the oven.

Processes and Manipulations.

Processes and manipulations. (645.) The first processes are immediately connected with the preparation of the *body*; in the language of the workman, the *clay*.

The *clay* for the body of the Oriental porcelain is prepared by a very laborious method. In paved tanks or pits, of some extent, men tread together the component earths, (much like treading plasterer's mortar in England,) until the mass is tawed or kneaded to a proper consistence; and during this very important process for securing fine ware, the workmen reject every particle of heterogeneous substances which they observe, whether introduced by accident, or by the adulteration of the cakes of mineral by the miners; because, it has been proved that hair, sand, or air bubble, will spoil the article in which it occurs. Portions of the well-trodden

mass are then manually rolled various ways on slabs, to render it homogeneous, and adapt it for the subsequent manipulations. (Wedging and slapping clay are kindred processes.) The *glaze* is prepared by more operose processes. The impalpable powders of petuntse and she-kao, (calcined gypsum, plaster of Paris,) are in proportions mixed in water; (by the workmen every liquid is named an *oil*;) calcined carbonate of lime is slacked by sprinkled water, and its powder, placed on alternate layers of fern, is repeatedly burned; and one per cent. of she-kao (calcined gypsum) is added to this in a suitable quantity of water. The two liquids (or *oils*) are next mixed, when of equal density, in the proportions of 90 of the former with 10 of the latter.

How little have those professed Chemists consulted their own credit who have literally copied the worthy Jesuit, Father D'Entrecolles's accounts without reflecting on their special import. The repeated calcination renders the lime more caustic, increases the dose of potass, and better adapts the glaze, not only of itself to fuse, but more effectively and readily to bring into fusion the surface of the ware on which it is laid.

Of the processes for the Dresden ware, we only know with certainty, that the clay is mixed with rain water at the equinoxes, when of a certain temperature, and when it is conjectured to be less adulterated with adventitious matters; and the ware is baked with only well-dried white wood, whose alkali, combining with that of one of the components, promotes vitrification.

The materials for coarse pottery are prepared by a very rude and ancient method. The place is technically named a *sun pan*. A level plot of land is enclosed by banks, and the inside of the boundaries is lined with planks or bricks; the bottom is formed of the ground. Upon this is scattered a small quantity of fine water-washed sand. At one corner is a square hole of about two feet and three feet deep, the sides of which are also lined. Into this the materials are cast and covered with water; then

Manufactures.

a blunger (see Art. 648.) is forced down, and the mass is very violently agitated to loosen the pyrites or gravel, that the larger particles may subside. When the mass has formed a semi-fluid, the workman lades it out with a small pail, and pours it through a hair sieve, which he agitates with one hand; and the particles which do not pass through are cast aside into the road. This is repeated until the bottom of the sun pan is covered to the depth of four inches; and then, at intervals of from two to four days, as the evaporation has proceeded more rapidly or slowly, additional quantities are poured on till the mass is twelve or fifteen inches thick; when this has acquired the consistence of strong dough it is cut out and placed in a vault for use. This method, vague, uncertain, and at variance with all scientific accuracy, is likewise practised in some manufactories of flint ware; and, to a very ignorant man, who mixes barrowfuls, not seldom does the manufacturer trust for the quality of the clay which forms his ware.

Slip making.

(646.) *Slip making*.—In the preparation of the clay for best flint ware, porcelain, and the beautiful ornamental bodies, for the sun pans is substituted the *slip kiln*. The *slip house* is a long building, usually separate from all others, of one story height, with the tiles of the roof laid half-way asunder, the more readily to allow the escape of the steam and vapour. In some of the manufactories, however, it is placed in the cellar or ground-floor. Unless two kilns are requisite, one part of the building is wider than the other; and in this are placed on the ground, on one side, large flags, for the process called *wedging* the clay; and on the other, deep *blending* or *blunging* vats of ascertained contents, from four to seven feet by three to six, and from two to four feet in depth, and marked by a graduated scale, with the sides formed also of very strong flags placed edgewise, and firmly cemented and clamped with iron. In each is placed a pump, for purposes hereafter mentioned.

Slip kiln.

(647.) The *slip kiln* (shaped like a brewer's cooling back) is a long trough or evaporating vessel, formed of particular shaped fire-bricks, the length of which is fourteen, eighteen, or twenty-two inches, the breadth ten inches, and the thickness six, four, or two and a half, according to the purpose, and their contiguity to the fire mouths. These large bricks rest on ranges of single common fire-bricks, laid so as to form separate flues for the heat, the whole length of the trough; and the outer range is firmly laid, and brought up to form sides, from twelve to eighteen inches above the surface of the kiln bricks; and the breadth of which trough is from four to six feet, the length from twelve to twenty-four yards. To prevent soot or smoke affecting the mass while evaporating on the kiln, the fire-places or mouths are at one end, outside of the building, and separated by a wall from the kiln; and the flues are continued into the chimney at the other end. The bricks being slow conductors of heat, the evaporation is of course comparatively slow, and the heat is more gradually communicated to the semi-fluid mass.

The slip kilns for porcelain clay, and those for ornamental wares, are made by a thick coating of calcined gypsum or plaster of Paris being run upon the bricks and on the sides, and thus is produced a slow evaporation; but the additional expense of the kiln is regarded as trifling, compared to the advantages of the clay being rendered more uniformly consistent during the very slow evaporation to which it is exposed.

(648.) The *blunger* (or blender) is formed of ash plank, seven feet long, sawed bladewise; the upper end is eight inches broad and two thick; the top shaped to a round form, on which is firmly fixed a cross piece, or transverse handle; the other end is about six inches broad by one thick. Another *tool* is rather like a baker's peel, with a spade handle, and a large *wooden mallet* is also used in the slip house.

Mechanical Processes.
The blunger.

The necessity of separate preparatory places, slip house, &c., is a result of the varying recipes being different, in each manufactory, in quantity as well as materials. The manufacturers of Kingtching obtain their materials in readiness for washing and combining as clay; and those of France purchase theirs from establishments at Limoges; reducing considerably the working capital requisite, as the body and glaze, in both instances, are prepared on the spot where the earths are quarried. But, as previously mentioned, each manufacturer can vary his components at pleasure, as suggested by experience or inclination, when the body and glaze are prepared by himself, or on his own premises.

That the ware may be of a certain quality the manufacturer directs the precise quantity of each component, which the slip-maker carefully takes of each kind of clay first: these he casts into a certain quantity of water in the blending vat, whose dimensions are known. The blunger is next pushed along the bottom of the vat a few times to loosen the mass; afterwards, after pushing it along, the man rests its flat side against the edge of the vat nearest him, and by the cross handle with both hands he forcibly raises the blade end, and whatever it touches, up in the water, and continues this laborious process until the whole of the semi-fluid has the uniform consistence of thick cream, and the density of twenty-three ounces per imperial pint; this being attained by adding water or clay, as needful. Inattention to this, and also to the addition of equivalent components when the mass has been increased, has frequently caused great losses in the baking. By the levigation in this vat will be loosened all gravel or larger pyritous matters not abstracted where the clay is quarried; these settle at the bottom, while the more completely to abstract less ponderous particles, the semi-fluid is pumped out of the vat, into a silk lawn sieve, which allows only those particles which are in a state of proper comminution to pass through into another vat, also of determined capacity. Into this vat, also, is pumped the proper quantity of Cornish clay, or kaolin felspar; and also of ground flint, each thirty-two ounces per pint, lawned; the blending is resumed, and the whole is pumped out and passes through the finest lawn, and in this intimate state of intermixture, free from all grosser particles, the semi-fluid runs upon the *slip kiln*.

(649.) *Clay-mill*.—The application of Machinery to this process has been successfully made in several of the manufactories where the power of a steam engine was at command. The *clay mill* (pl. xlviii. fig. 1) is formed of two strong cast metal parts of a conical figure, four feet high, and twenty-eight inches diameter at the wide end, and eighteen at the narrow end. These are firmly screwed together by flanches at the edges A A, and are placed with the narrow end downwards, firmly closed with a strong bottom, on which rests a brass step, and having in the side an aperture, like a parallelopiped, about eight inches by six. In this metal section, at certain dis-

Clay-mill.
Pl. xlviii.
Fig. 1.

Manufactures. tances, determined by the curve lines of a spiral, are screwed very strong blades C C, of varied lengths to reach near the centre, half an inch thick on the back, about one and a half broad on the blade, inclining to an edge, and tapering to a point. This is the passive part of the Machine. In the step on the bottom revolves the active part, which is turning an upright or vertical shaft E, moved by a spur wheel, in a collar step near the top. In this shaft are screwed, at right angles, similar blades D D, which radiate near to the sides of the cone, but arranged with such parallelism to the others as to traverse the space immediately near them, and act with the effect of shears on whatever substances intervene; but their flat sides form the lines of a spiral, and agreeably to its form and force, by every succeeding revolution, they cut the substances very small, and press them out at the aperture.

The flints are subjected to different processes. The nodules are calcined in a small kiln, resembling in form that used for lime, and while hot they are broken into small pieces by the miller, and then cast into the flint pan. Where mechanical power is available, the breaking of the nodules is effected differently. The object is to unite weight with percussion, on the principle of the pile engine, the accelerated fall of a heavy loaded beam. About two feet from the ground is firmly fixed a very strong iron grate, on which are thrown the flint nodules while incandescent. Above this grate are properly ranged, vertically, three stampers or wood beams, twelve feet long, six inches square, the lower end strongly shod with iron, and the upper has a projection or strong catch pin resembling a stamping-mill. (Art. 225.) The line shaft is supported by a step in the wall of the mill; and on the end is a walloper wheel, provided with three wipers or crank-like projections, about eighteen inches or two feet diameter, that catch and raise the stampers in succession; and these, when left free by the rotation, fall with great force and break the flints small, and the fragments fall through the grate and are thrown into the flint pan.

Flint pan. (650.) The *flint pan* consists of a circular vat firmly hooped together, and from eight to ten feet diameter, and twenty-four to thirty-six inches in depth. The bottom of this vat is paved with small blocks of hornstone, quartz, or felspar, as preferred, laid firmly in some mortar of the material to be ground. In the centre moves an upright shaft, on the upper or lower end of which is fixed the spur wheel; and a strong firmly fixed hoop or barrel, about fourteen inches high, surrounds it inside the vat, to prevent injury to the materials. At right angles to this shaft are four very strong arms and grating framework, on the bottom of which is a ledge, and round which is a slug-iron, to bear the *runners*, very large blocks of the same substance as the *pavers*. Water is put in to the depth of eight inches, and the broken pieces, flints, Cornish stone, or felspar, are thrown in, and the whole being put in motion are abraded against each other, and the pavers and runners, in the water, till they are reduced to very fine particles, and the fluid has the consistence of thick cream, with a density of thirty-two ounces per imperial pint. The constant forcing of the whole mass in contact with the hard stones abrades also a portion of these latter, and the manufacturer has to calculate on the presence of this heterogeneous substance in his mixing. One ton of good nodules should grind into one hundred and twenty pecks of flint pulp.

Mechanical Processes. The selection of pavers and runners demands considerable attention. Whether grinding flint, Cornish granite, bone, felspar, or glaze mixtures, there will be some minute portions abraded, which to a certain extent affect the pulp. During many years the Derbyshire hornstone (technically named *chert*) was used; but ignorance on the part of the millers caused some to be employed, in which carbonate of lime was present in extra proportion, and its mixture with the flint rendering the flint ware fusible at a heat lower than usual, several ovens full of ware were fused down before the error was discovered. Other instances were ascertained of the pavers being calcined among the flints, and ground therewith, in consequence of which the ware *rifled*, and the law had to determine which party should bear the losses. The chert of the Halkin Hill was found very excellent, and is now preferred; but however free from lime, as it abrades, though less than flint, in 1832 pavers and runners of granular quartz were introduced in many flint-mills; and in 1834, the green felspar or kaolin, previously calcined, was first used for grinding materials for porcelain bodies; and the fawn-coloured, or white Middletown Hill, previously calcined, for best glazes.

The Cornish granite for body and glaze, or petuntse, is ground to the weight of thirty-two ounces per pint; the felspar for body, to the same weight; but for glaze to twenty-eight ounces. The glazes vary with the nature of their components, and are adjusted in the hand glaze-mill.

When the flint nodules are reduced to a pulpy state, the semi-fluid, is poured into a *washing pan*; a smaller vat, with a lighter shaft and radiating framework, and small arms similar to a capstan, by which the pulp is agitated violently in an additional quantity of water, which carries away any soluble salt of iron, and also allows the more weighty particles of the clay to subside, to be again thrown on the mill. The fine pulp is then poured into additional water in an ark, one of the sides perforated with holes for plugs, which can be in succession drawn as the pulp increases in density, and the water also carries away another portion of iron. Cornish granite and Middletown Hill felspars are similarly washed; and when the former is dried on a kiln, much like the slip kiln, it is technically named *composition*. The felspars are similarly dried.

(651.) *Blending-mill.*—The small lumps of clay from the clay-mill are cast into the *mixing* or *blending-mill*; (fig. 2;) a circular vat, D, about seven feet in diameter, and three feet deep, within which moves a vertical shaft A, that has four arms of wooden framework B B B B, radiating at right angles, and which resemble strong gates; these, when put in motion by the wheel E, violently agitate the whole, so that while the denser particles gradually sink till they are lowest in the semi-fluid, the finer particles remain suspended, and are yet more intimately intermixed, by being passed, with the proper quantity of flint, through successive lawn sieves of increasing fineness, at the end of each spout, agitated by cranks and belts, and then conveyed upon the slip kiln.

On the slip kiln the semi-fluid is subjected to continued heat, which causes constant ebullition, until the surplus water is slowly dissipated in steam and vapour. Attention is paid by the slip-maker to keep the semi-fluid in agitation during the early part of the process,

Blending-mill.
Fig. 2.

Manufactures.

that the greater specific weight of the flint may not be allowed to operate in its subsiding, and thus be found plus in one portion of the clay, and minus in another, of the same making; also, to prevent the mass next the bottom becoming hard and the upper more fluid, by the expulsion of the moisture, and the subsidence of the particles, as well as because of the reciprocal tendencies of silica and alumine, which, when humid, readily assume the consistence of mortar, that speedily hardens, and in a short time assumes a solidity which the subsequent action of the atmosphere does not easily affect or decompose. When the cessation of air-bubbles on the surface, and the homogeneous appearance of portions cut out of different parts of the mass on the kiln, lead the slip-maker to consider it as adequately evaporated, and of the consistence of strong dough, and sufficiently hard, yet not too hard, to properly yield to the hand of the thrower in his manipulations, or of the presser's beater in preparing it for the moulds, the fire is abated, and the mass is quickly removed into the other part of the slip house, where it is subjected to the process of *wedging*.

The process of blending appears to need simplifying on some regular plan. The laws of chemical combination determine the reciprocal tendencies of substances; and these being known, as well as the proper density of their mixtures, whether clays, flint, Cornish granite, or felspar, it seems requisite that the density of the clay mass or body should also be determined; in which case there might be a ready way for mixing, by putting into a gauged vat a certain quantity of water, and a specified weight of each material component; the mixing-mill would of course beat the whole together, and if allowed to run over into spouts and lawns the final lodgement would be on the slip kiln. The reduction in volume of certain substances in combination precludes all certainty of calculations, so that these can only be verified by comparison. There is a certain rule for determining their specific gravity, which may be thus briefly stated. The specific gravity of bodies is as their weights divided by their volumes; and the mean specific gravity is the quotient of the sum of the weights divided by the sum of the volumes. Make the two weights W, w , the two volumes V, v , the two specific gravities P, p , and the calculated mean specific gravity M ; then

$$M = \frac{W + w}{V + v} \text{ and } V + v = \frac{W}{P} + \frac{w}{p} = \frac{Wp + wP}{Pp};$$

$$\text{hence } \frac{W + w}{V + v} = \frac{W + w}{\frac{Wp + wP}{Pp}} = \frac{(W + w) Pp}{Pw + pW} = M.$$

The slip-maker may most carefully observe his instructions, and also the several components be in strict accordance with the principles of mixing, likewise in precise proportions, and yet the clay be deficient in the adhesiveness indispensable for the workman to use with the greatest advantage to the manufacturer, and with only the usual trouble to himself; frequently the presser, to his great inconvenience, found that the *clay bat* would not hold together sufficient time to be lifted from the beating slab to the bench and mould. No remedy for such a disaster is suggested by the chemistry of atoms; and the chemistry of masses has not been regarded with minuteness adequate to present theory for the cause and effect; consequently practice only was left for explanation, and experience teaches most efficiently. The workman had frequently noticed

that the clay in which was mixed with the fresh components some quantity of *old* clay, (or which had been used by the thrower and cut off by the turner,) produced a greater quantity of sound ware than clay made wholly of fresh materials; and, on the supposition that a body which had been once worked would more readily amalgamate with the fresh material than with all of the latter only, the introduction of a certain quantity of turner's shavings into the blunging vat verified the supposition; and thus the surplus clay on the vessels becomes a second time available, and renders the mass adhesive for any manipulation. The practice was particularly requisite when the Middletown Hill felspars were first introduced. The components were carefully mixed and made into clay by the slip-maker; which clay the thrower formed into strong thick vessels, and left them to the requisite evaporation, and the green state, the reciprocal chemical action of the components in giving up their water; the turner next cut the vessels completely away in thin shavings, which were again carefully added to a certain quantity of fresh materials previously blunged and lawned by the slip-maker; and of these was formed clay for the best porcelain, which was suitable for the workman's purposes. In the preparation of the clay for the Sevres porcelain, however, there is found a necessity to add a certain proportion of baked ware, again ground into an almost impalpable powder; and in deficiency of this, the materials are formed into thin stilts, baked well, and ground; and only after these processes can the clay be worked. The reason of this intermixture is given under the directions for making seggars, and in the statement of properties essential to the body of chemical utensils. The person who first introduced these felspars, and who thus was the first to supersede the use of the noxious and most deleterious article *lead* in pottery glazes, was James Ryan, F.S.A. who suggested the following process as adequate to the purposes of the additional biscuit materials of Sevre ware:—Let the large blocks of felspar be well calcined by wood, turf, or fern in a kiln like a limekiln; and use these blocks as *pavers* and *runners* in the mill which grinds the felspar; and as all the contents of the vat will then be of the same kind of materials, the small portion abraded off the calcined blocks in grinding the other will be found usually equivalent to the baked component, and when any biscuit pieces are not saleable, they need only to be cast again into the vat, in certain proportions with the fresh felspar, and again they are useful, instead of being cast on the heap of potsherds.

(652.) *Wedging* is the next process; and is, in the published descriptions, confounded with *slapping* the clay for the thrower, or by the presser. When the clay is properly evaporated, it is carried from the slip kiln and laid on the flags above described; but as it then contains a great number of air-bubbles, these, although very minute, must, in the manipulations, be burst and destroyed, because, were they left in the clay, the air they contain would be so rarefied during the baking of the ware as to expand that portion of the vessel; and when the bubble burst, either a blister or a crack would ensue, either of which would depreciate, if it did not completely spoil, the ware. To accomplish this effectually, instead of *treading* the mass like mortar, as is practised by the Chinese, a mallet is used to beat it together, and so prepare it for being cut into small pieces by the spade-like tool described Art. 648. From different parts of the mass, the person in succession cuts off a small piece, which he

Mechanical Processes.

Manufac-
tures.

forcibly casts down, and repeats this laborious process till all is formed into a heap, thereby admitting the action of the atmosphere on the small portions to mellow each by thorough cooling, and also bringing the whole into one state of equal density, so that, wherever it is cut, the intersected portions will present a smooth homogeneous appearance.

Where there is steam power, a mill, like that used to break the crude clay, only with rather broader blades, is employed to supersede the manual labour of *wedging*. This mill not only performs the cutting equal to the parting it by the tool, but also the beating with the mallet, and the wedging it by casting on the heap. The repeated separation of the mass by the revolving blades destroys all the air-bubbles; and the constantly increasing pressure from their spiral arrangement, in the contracted space, gradually solidifies the mass, and renders it more and more compact, until, in one homogeneous mass, it is forced through the aperture, resting on rollers on a table, and an attendant, employed in some manual process, cuts it into brick-shaped lengths of about half a hundred weight, and places each in a vault until the workman needs it.

All pressure and mechanical means adopted are found, however, incapable of effecting that intimate combination which results from the mass lying some time before it is used. After the clay therefore has been wedged, it is placed in the vault to remain as long as the conveniences of room, capital, and time will allow, before it is employed in the fabrication of vessels; and the longer period it remains, the better is it adapted for the purposes alike of the workman and the manufacturer. We have heard that Wedgwood's jasper body lies never less than six months; yet, many persons, though fully aware of the advantages of delay, preferring an immediate turn of capital to a greater but more remote benefit, if they do not resolutely oppose the practice, or have not capital to keep up a large stock, may have ware manufactured of clay taken into the work rooms reeking hot from the slip kiln, and after an interval of only a few hours from its being in ebullition. Can there be any wonder that great losses in the baking are consequently incurred?

At Etruria by Mr. Wedgwood, first, and at Stoke by Mr. Spode, next, the power of the steam engine was applied to break the calcined flint nodules by stampers; to grind them in water, to cut the crude clays, and mix the components in blending; to move the lawn sieves as the semi-fluid passed to the slip kiln; to cut, mellow, and wedge the evaporated clay, and to drive the wheels of the thrower and turner.

Slapping.—The clay used by the thrower is placed on a strong bench, and a man with a brass wire cuts off a piece many pounds weight, which he lifts up, and with all his force violently slaps it down on the mass; and this is frequently repeated until it is apportioned by the *baller*.

Throwing
of porcelain
and pottery
Fig. 3, 4.

(653.) *Throwing of porcelain and pottery.*—The *thrower's engine* or wheel (fig. 3) is a box-shaped frame D, fitted into one corner of the room, about a yard in diameter, and with a curved front. In this is fixed, in a firm frame, a spindle or axis B, working vertically in a collar C and step E. Near the step is fixed on this spindle a multiplying wheel, with the pulleys of different diameters for changing the speed, as the vessels made are more or less heavy. The top of this spindle has the head A firmly fixed thereon, and around is the space for the

Mechanical
Processes.

workman's feet on each side; in the corner is a seat for him, and the front allows full scope for supplying the clay and taking off the formed vessels. At the distance of four or five feet near the ground is a guide pulley F, under which passes the driving cord to the rim of the large wheel G, at four or five yards' distance, and to which, by a winch on its axis, motion is readily given by a proper person.

Where steam power is available, we find two cone drums (fig. 4) placed inversely, on parallel shafts A A, employed to give motion to the thrower's engine, for forming those large vessels in which manual labour would be expended to great disadvantage. The main shaft, or horizontal spur gearing, has a fixed bevel wheel which works in and moves another bevel wheel B on the top of one of the vertical shafts; and at the bottom of the other vertical shaft are two pulleys for a belt, one firmly fixed to communicate motion to the thrower's engine, the other loose, for the belt to remain on during the cessation of motion. On these two shafts the cone drums, of exactly the same dimensions, are fixed, with the apex of the driving drum opposite the base of the other. This relative position allows a broad leather belt D to traverse the whole extent from either extremity to the other, and yet be always tight; only the motion of the driving cone, when the belt is near to its base, giving the maximum velocity to the other, whose apex it traverses; and this velocity diminishes as the belt ascends to the apex of the driving cone, on which it is at its minimum; the thrower's engine accordingly has varied velocity at pleasure, by the position of the driving belt; this is effected by a simple contrivance of a directing lever, with a guiding loop-hole, which a boy with a winch moves, agreeably to the thrower's instructions, and by practice is so intimately acquainted with the manipulations, as easily to adapt the velocity to the work in progress, and when this is completed to the satisfaction of the workman, to direct the belt on the loose pulley and stop the Machine.

At a bench near the throwing engine stands the *baller*, usually a young woman, before whom is a large lump of clay. From this, with a brass wire, is cut small quantities, each of which is weighed, when the body is valuable, and the vessels must be of a determined size; this is then well slapped between the hands to expel water and air-bubbles, and formed into a ball, which is placed nigh the man, or put into his hand, as the ball is small or large in size.

On the seat in the corner of the frame already mentioned, the man places himself, with one foot on each side of the wheel head, and his knees supplying rests for his elbows, when his arms require to be very steady. The great numbers of vessels of the like dimensions and shape constantly requisite to be formed, (and which we scarcely need mention must necessarily be of a *circular* kind,) is ensured by the man placing his gauge, a peg or stick, in a lump of clay, at a certain distance from the centre, to indicate whenever the plastic figure coincides in the requisite height and diameter, and the vessel has attained the proper dimensions.

The thrower directs the person at the large wheel, by the word *turn*, to the velocity he requires. He then very forcibly casts on the wheel head a ball of clay, which with both hands, previously wet, and at intervals dipped into water near him, he repeatedly squeezes up into a high conical column, which he forces down again into a lump, until there is little probability that any air

Manufac-
tures.

bubbles can remain in the mass. With one hand, or finger and thumb, *in* the mass, and the other on the *outside*, or with his fingers only, he gives the first rude form to the vessel, and by a swage, rib, or other utensil, that has the profile of the shape of the vessel, smooths the inside, gives the proper shape, and removes the *slurry*, or the inequalities left by his fingers, until it is completed to his satisfaction. With a piece of fine brass wire, with a handle at each end, he quickly cuts off at the base the vessel thus roughly formed; the baller hands him another ball, and with great facility lifts off the vessel, and places it on a board, on which it remains (occasionally turned upside down) until all on the board dry gradually to a certain consistence, which is called the *green state*, because it is that when, more than at any other, the clay possesses tenacity and firmness to bear without injury the subsequent manipulations; it being only when in this state of complete chemical reaction of the silicic acid, alumine, and water, that turning, smoothing, fixing the handles, spouts, ornaments, and other appendages, can be effected.

Jigger
described.

(654.) The *jigger* also, called a *throw* by Mechanics, is larger than, yet much resembling, a lapidary's wheel, having a vertical spindle, with a winch, pulley, and belt fixed to work in a bench, and a block to fix firmly on the top of the spindle; this is used to give motion to plaster moulds placed on the block, while making circular dishes, plates, saucers, shallow bowls, and many other vessels, and also many oval *hollow-ware* articles. In some manufactories, the throwing engine is employed for this purpose.

A considerable number of pieces of clay, of a determined size and weight, are batted for the purpose, (see Art. 659.) corresponding to the number of moulds at liberty. A mould is placed on the head of the throwing engine, (or on the block on the top of the jigger,) and motion being communicated, on it is laid one of the bats of clay, which the workman's hand presses close to the mould, and thus gives its interior shape; next, as the motion continues, its exact figure and thickness are regulated by a swage or profile and wet sponge; and, when a ledge is required, a thin strip of clay is laid on with slip; (and any feet are added, as described under *handling*;) all extraneous matter is cut away, and a horn tool and damp sponge are used to finish the article. The moulds are placed in regular succession in a stove, and when properly dry, the bats are taken off, the edges are carefully pared, the last polish is given by slightly passing the hand over the pieces, and in *bungs* (piles) of more or fewer, as heavy or light, they remain in a drying place, until they are ready for being placed in the seggars to be baked biscuit.

Turning.

(655.) *Turning*.—This manipulation requires considerable dexterity in the workman, to avoid destroying or fracturing the vessels, while forming them to their requisite size, thickness, and correct shape of circular vessels; and it presents numerous opportunities for the exercise of skill, taste, and genius, in giving to the several parts the rings and rims required, and to the whole all the elegance suggested by the pattern, and the little niceties, either with much difficulty, or by no effort, obtainable when on the throwing engine.

The *turner's lathe* has much resemblance to that used by wood turners; but the spindle is longer, the crank on the wheel axle describes a larger circle, and the treadle is differently formed, with a cross piece, that the treader may with more ease produce, and,

as proper, regulate the motion required by the vessels, while the turner stands steady in performing his manipulations. On the crank axle, below the cheeks of the lathe, is fixed a rather heavy wheel, about three feet diameter, and in its rim are three grooves for the cord to turn the spindle; a wainscot partition separates it from the space into which fall the turnings while the work is in progress. The end of the spindle outside the collar step and headstock is formed into a screw, to which are fitted a number of *choques*, each tapering gently, and in diameter adapted to easily fit the inner surface of the vessels which need turning. Near the headstock is a small shelf, on which the treader keeps a supply of vessels, to prevent delay to the turner.

Mechanical
Processes.

The *engine lathes* are constructed with the collar step, readily movable horizontally by a spring, between two check screws, and with a catch pulley (varied in size for the incision of the plate) fixed at pleasure; against this strikes a circular iron plate called a *movement* fixed on the spindle, and in whose edge incisions of more or less extent are formed at certain distances, so as to give to the spindle slight horizontal and vertical motion during the rotary motion caused by the wheel.

At the Etruria manufactory, and at one at Stoke upon Trent, belonging to Copeland and Garrett, are rooms in which the lathes are placed in rows, and the motion is derived from the steam engine at each. Near the ceiling and one wall of the room runs horizontally a general driving shaft, on which are fixed the same number of small drums, about eighteen inches long and two feet diameter, as there are lathes, and from each drum is a belt to the fixed pulley on a small shaft below, placed lineally with the spindle of the lathe. This shaft has also two loose pulleys with sliding collars and catch gearing, to be at pleasure set in motion by the fixed pulley. From the pulley a cross belt passes to a pulley fixed on the spindle. The pulley is of three sizes, corresponding with another pulley counter-placed on the spindle, so that the belt fits wherever it may be guided by the turner, to increase or diminish the velocity of the spindle as he is proceeding with his labours. When these are perfected as far as the *turning* is requisite, the pulley is thrown out of the gear, and the other with the cross belt is set in, and gives to the spindle retrograde motion, by which the vessel is smoothed, solidified, and polished, as subsequently explained.

The turner's tools are of iron, thin and well forged, usually about eight inches long, with a sharp part to fit into a handle when worn very short. Their breadths differ from a quarter of an inch to two inches, and the cutting end is turned up at a right angle about half an inch, and then on the grindstone, or by a file, the inner edge of the turned-up part is made sharp and truly level.

A little raised above the treadle by a block or seggar, stands the treader, at the end of the spindle, so as to have entire command of the lathe cord, and be able easily by mere pressure down of the treadle by the foot to give adequate motion to the spindle and the vessel on the *choque*. Near the treader is a board bearing the vessels which require turning, and as the workman is employed in his manipulations, the treader is also further employed in moistening the upper edge of the vessel, and clearing away whatever may risk its turning, or delay the operation; and on this being done each vessel is placed on the small shelf already mentioned.

Manufac-
tures.

The position of the turner while employed on earthen ware is the reverse of that of the wood turner; for instead of standing exactly linear with his lathe, or aslant a little from the headstock, he looks towards this, and remains at entire freedom from every thing which might render him unsteady. On the choque is a clay ring, kept scarcely moist. The vessel to be turned is put on the choque, and as soon as the treader gives motion to the spindle, the turner presses with his tool or finger the upper edge, already moistened, into the clay ring. Next placing his tool opposite the transverse axe of the piece, he carefully cuts away all surplus clay left by the thrower, and reduces it to the precise thickness required; (in very valuable articles the turner weighs each vessel.) The ornamental portions are formed, and, when engaged in *engine turning*, while the spindle is in slow motion, the back spring causes the incisions of the circular plate or movement to bring the vessel nearer to the tool, and those parts are in consequence cut away in diamonds, dice, or other fanciful indenting; and the full part carries it away again, so as to form these dice, &c. at distinct distances all round the vessel. When all the *cutting away* of the clay has been completed, the treader very expertly gives to the spindle a retrograde motion, during which the turner applies the flat surface of a broad tool on the upper part of the vessel, and by gentle pressure thereon gives to the whole vessel a solidity not previously existing, and a glossy smoothness of surface, removing all inequalities left by the prior manipulations. The vessel is next cut loose from the clay ring and placed on a board for the handler, or to dry for the biscuit oven.

Handling
and figur-
ing.

(656.) *Handling and figuring*.—These manipulations fix on the clay vessels their handles, snips, spouts, ornamental figures and foliage, and whatever other required additions are to be made after the manipulations of throwing and turning. For the best sort of vessels these are first formed in moulds, (Art. 659.) of which an adequate number are in the charge of the handler, and kept placed around the stove, that they may prepare another succession of the articles while he is affixing in their proper places on the vessels those previously abstracted.

Fig. 5.

But for readily forming the handles for less valuable vessels, jugs, &c., recourse is had to a small Machine called the *squeezing box*, fig. 5. An iron cylinder A, six inches in diameter and twelve inches deep, with a very strong bottom, whose centre has an aperture about one and a half inch diameter, is firmly fixed in some place, conveniently high, and of ready access without disturbing any other arrangements. Screwed or riveted to the upper edge are two inch square iron bars, six inches long, on the top of which is screwed a cross piece B, the middle of which is very strong, and perforated with a female screw, in which the other cross piece C works, cut fine or coarse, as the process has to produce a very solid and fine article, or one of less value. On the upper end of C is fixed a transverse handle D, and the lower end works in a socket in the piston E, a plate of strong iron, turned to the exact size of the cylinder. In the aperture in the bottom can be inserted pieces of lead, in each of which is pierced the size and section of the handle, agreeably to the taste and desire of the manufacturer; and in this is fixed a steel pin, vertically, when tubes for the purposes of the chemist, or for ornamental tobacco pipes, are to be formed, but not necessarily so in all cases. The piston being screwed up above the

Mechanical
Processes.

box, a quantity of well slapped clay is put in, the piston is then screwed down on it, and when its force is fully exerted, a portion of the clay constantly exudes through the hole in the lead piece, and is received on a board the whole length; and thus are formed a number of strips of clay which are left to dry a short time; they are next cut into proper sizes, bent into the requisite shapes, and left to dry a little longer.

The handler prepares his spouts, snips, handles, &c. in regular succession, by cutting away (with a sharp knife of the kind used by cordwainers) from the edges or ends every little portion of superfluous clay. For placing on the handles, he cuts level a small space of the proper size on the curved surface of the vessel, and for the spouts, (as of tea or coffee-pots,) with a sharp-pointed knife he either cuts out an orifice, or forms a grate of the size and shape of the larger end of the spout; and for snips of jugs, &c. a piece is cut out of the upper edge of proper size and shape. He next moistens the edges of the orifices and articles to be affixed with slip, then, while they are moist, places them in contact, and they remain a few minutes undisturbed. Again they are inspected, and, when requisite, a little slip is added, and by gentle pressure with a proper tool they are brought properly together, whatever parts were not joined previously; but when found completely connected they are left till sufficiently dry to bear holding in the hands, as the knife is applied to trim off all excrescences. The vessel is rubbed over with a moist sponge, to take away any dust or adhering matter, and to moisten the whole equally, so that the appearance may be uniform, and no injury ensue, while gradually drying prior to being placed in the seggars. But in using the sponge in this manipulation considerable attention is indispensable, because not unfrequently has the sponge been so often applied, that much of the alumine has been taken away, and the silica left, to which the glaze would not adhere in glaze baking, and dry spots have been formed on the outer surface, rendering the vessels of little value.

The *figurer* is usually a workman of extra dexterity and some genius. He mostly has in his train a youth, to whom this is a preparatory lesson as a *presser*. Into moulds of plaster, (see Art. 659.) or, when great numbers of the subjects are required, of copper, always oiled, the more readily to *deliver* the relief, for convenience and facility, soft clay is pressed, to form the figures, foliage, animals, and other beautiful subjects, in relief, exhibited on vases for chimney mantels, &c., and on the more valuable kinds of jugs, tea-pots, and ewers. When these are rather dry their exposed surface is cut quite smooth with a sharp knife, and then polished; afterwards they are taken out of the mould, left a little to dry, and then moistened with slip, placed in proper positions on the vessels, allowed again to dry to bear trimming off, and then they are finished for baking.

Great attention and care is employed by the modellers and figure-makers in their imitations of the foliage and petals of plants in porcelain, each often requiring a separate mould; and occasionally this is inapplicable, and must be supplied by manual dexterity and ingenuity. To properly, and with more ease and facility, effect this, there is mixed with the clay some starch powder, or other mucilaginous substance, which renders it more adhesive while being worked, but increases its beautiful and porous appearance after being baked.

(657.) *Modelling, mould making, casting, and pressing*. Modelling.

Manufac-
tures.

—These manipulations have immediate connection with the forming of all vessels, jugs, beakers, &c., not circular, or not plain on the surfaces.

The *modeller*, having to supply *blocks* of all new patterns and original productions approved by the manufacturers, he forms, according to the intention, in clay the true image required; or when at liberty to indulge the exuberance of his fancy, with due regard to propriety, elegance, and accuracy, he executes in his best style the offspring of his genius, and with tools of steel, box, yew, and bone, carves, trims, touches up, and re-touches the various parts, until he has finished the whole in the state of perfection desired, or according to the adequateness of his remuneration. These are frequently works of considerable skill and art, and in their invention and production the proper portion of genius ought constantly to be exercised.

Gypsum, or native sulphate of lime, usually called *plaster of Paris*, supplies the material for the formation of the moulds. The crude rock is ground in a mill between a pair of stones resembling those of a corn-mill. It is afterwards placed on a small kiln or trough similar to the slip kiln, having flues beneath by which it can be heated; on this the whole is *boiled*, that is, the water of crystallization is dissipated, leaving the mass a soft, impalpable powder. The man who superintends the mill usually protects his mouth by a double silk handkerchief, to prevent any particles being inhaled or swallowed, by which his lungs would become charged and his stomach disordered, disasters very injurious, and which often have arisen to the careless. The plaster retains a powerful tendency to solidify quickly, but not to crystallize, when supplied with a certain quantity of water, which adapts it for being readily cast into moulds, as well as for being employed in the manufacture of various articles. Naturally absorbent of water, this property is further promoted by the moulds being kept at a high state of dryness on shelves around a stove in a small apartment; and whenever there is little tendency for the components of the body, (and even when there is much it is counteracted by a size, or the dust used by the presser,) the clay can be applied several times daily.

The *mould maker*, quite distinct from the modeller, is usually a man of considerable judgment, who has to form the plaster moulds, so that they will readily separate into parts for greater facility and correctness in producing the intended vessel or figure. He has to exercise much care in making those for the dish-maker and presser, but especially those for the *casting* of figures, &c. The block or model is placed on a board of proper size, and at the distance of the intended thickness of the mould is securely fixed a strong *cottle* or clay bat. A certain portion of the block or model is also covered with clay, and the exposed portion is covered with a coating of size made of 1 ounce of potash, 1½ ounce of soft soap, and 2 ounces of China clay, boiled slowly in a pint of water half an hour.

The workman then takes a certain quantity of water, (and for some particular moulds adds urine,) into which he puts by measure a proper quantity of plaster, which he quickly and briskly mixes together, and then pours the semi-fluid around and over the model until the upper part has the designed thickness. The combination of the plaster with the water evolves some heat, which increases during a few minutes, until the mass is sufficiently compact to bear removal; it remains a short time,

and the clay cottle is separated, and in succession are all the parts of the model covered, and those of the mould formed. In a few hours the whole becomes a compact bibulous mass, easily separable from the model, and presenting a correct *fac simile* of even its minutest lines and ornaments. The mould is next placed where it can dry very regularly, and soon is ready for use; and when put near a stove may be five or six times daily covered with fresh clay bats, and so absorb moisture from them that in a moderate time they are so dried as to be a little contracted in size, causing the vessel or figure to slip out (and the mould is said to *deliver*) easily, readily, and perfectly; fresh bats are put into the moulds, and while they are drying, those taken out are undergoing the requisite manipulations of trimming and finishing.

(658.) *Casting* is adopted to considerable extent in the manufactories at Derby, Sevres, and Tournay, where all tea ware is cast, and several hundred moulds are used together. Where much beauty, delicacy, and niceness, but little strength comparatively, are indispensable, and there is particular need or desire to obtain the fine sharp lines and perfection of ornamental articles, and elegant figures, busts, and vases, this is allowed to present the most ready and accurate method of accomplishing the object. All the parts of the moulds fit so close that the semi-fluid is altogether retained; but, of some figures, distinct series of moulds are used for the head, arms, legs, and trunk, all of which are carefully joined together with slip, and finished when properly dry. Wedgwood's productions are deservedly celebrated in this respect. The body is diluted in pure water to the consistence of thick cream, and this semi-fluid is poured into the cavity of the mould, where it remains a longer or shorter time, as deemed requisite. The plaster immediately absorbs the moisture of that portion of the mass contiguous to the mould, and it hardens so as to be fixed in a stiff coating attached to the mould when the portion of the fluid is either poured or by a syphon drawn out. In a short time a more dense mixture of the body is poured in, and left rather longer than the former before it is poured out. The mould and what it contains are placed on a board near the stove, until the contents are sufficiently deprived of moisture to support removal freely, and present an exterior surface precisely corresponding with the original figure. The subject is placed aside till in the *green* state, and then the workman removes all redundancies, remedies all imperfection, and for its full completion exerts his utmost skill. When rather dry it is brushed from dust and carefully rubbed smooth with tow.

(659.) *Pressing* (often called, technically, *hollow ware squeezing*), is another, and very laborious, manipulation. On a bench are fixed some rings or cottles of clay, thick and strong, and into the space is poured a very dense mixture of plaster and water, which is left to combine several hours, (or days when convenient,) and after it is properly set, it is completely soaked in water to prevent the clay adhering to it, while being beaten or *batted*. The presser considers well the size of the mould he is to use, and the thickness of the articles to be formed. From a mass of clay before him, with a brass wire he cuts a piece of suitable size, which he repeatedly squeezes in his hands, forms into a ball, and forcibly casts down on the bench or board, to prevent any air-bubbles remaining in it. This he beats on the plaster block with a plaster batter, by an expertness and

Mechanical
Processes.

Casting.

Pressing
described.

Manufac-
tures.

dexterity only to be understood by being witnessed, and the requisite figure and thickness is thus given to a number of *bats*, for preventing the delay of forming each just when wanted to be put on the mould. After the bats have been prepared a short time the mould is placed on a whirler, the bat is put on it, and with a moist sponge is *bossed* (forced) into it; the different parts of the mouldings are similarly covered with a bat. When the mould is in one piece the thumbs are employed to work the clay very solid, and preclude its liability to crack, and to press it into the different ornamental parts and several corners. The great size and weight of the bats and moulds for large dishes render the manipulations so laborious, that a man and his assistant with great exertion can seldom make four per hour; neither do they continue their laborious employment the same number of hours as the other artisans. But some of the moulds have several parts, into each of which the clay is worked as above mentioned; the inner surface is rendered smooth with the moist sponge; with a sharp knife all extraneous masses are trimmed off the edges, and these are moistened with slip; all the parts of the mould are next put in proper connection together, and secured when requisite by a belt buckled round them. The finger is next drawn forcibly up every joint, into which afterwards is put a thin roll of clay, which is worked into the mass by the finger and thumb first, and next by a thick smooth leather, to render the clay smooth. With a sponge moistened with slip the wreathes or wales are expunged, and with another sponge moistened with clean water the inside is carefully washed; the mould is now to be placed a short time aside to dry a little, and again it is placed on the whirler and polished with a smooth thin plate of horn. The mould is next removed to a shelf near the stove, and there it remains until by absorption of the water and its evaporation the clay article will readily separate; and when in this state it is taken out and placed on a flag to harden a little, that it may be *fettled*, that is, by proper tooling and trimming, freed from all appearances of seams. All extra clay is cut away, the whole is rubbed with the wet hand first, then with the moist sponge, to clean it; the handles and other ornaments required are next placed carefully where proper, and the whole is polished with the horn, and placed to dry for baking.

In manufacturing porcelain, the articles, after being finished in the clay, are placed either on plaster flags ranged in the room to more gradually part with the remaining moisture; or on boards above the workman's head, or resting on props fixed in the walls, or ranged upon frames in small apartments solely appropriated and heated for the purpose, and committed to the care of the *looker to the ware*; a man on whose careful attention to the gradual rise of temperature from the last manipulation, until the several articles have the appearance in dryness and colour of the dried plaster of a new wall, depends the excellence of the ware; because the shape would alter, and the vessel probably become useless, did any part of it again become moist through a lowered temperature.

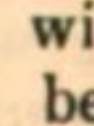
This subdivision of labour, by distributing the work among a great number of work-people, is proved advantageous in causing the whole to proceed rapidly with great regularity. Incessant attention to one operation solely, whatever it be, renders each artisan dexterous and ready in its performance, and no time is lost in changing implements; as when each man, to be called a good

workman, performed the distinct manipulations to *throw*, *turn*, and *stouk* (handle), as well as *fire*. But, as the celerity it is calculated to produce is unfriendly to the improvements suggested by genius, though useful in conducting every merely mechanical operation, possibly to it alone must be attributed the continued adherence of the workmen to old and faulty practices.

(660.) *Baking biscuit ware*.—This *first* baking is not with grammatic accuracy termed *biscuit*; (*bis coctus*;) but the application is regarded as having originated in the ware presenting to the view, and also to the touch, the dry and rather rough surface observed on sea bread.

The common oven remains as it has been used ever since the *salt glaze* ceased among the manufacturers. The *improved* oven is of recent adoption. Their characteristic difference is in the construction of the *hearth*, or what some might be disposed to call the *plinth*, which part of the fabric we shall fully describe.

In the common, and also in the improved ovens, the hearth *M* (pl. xlix. fig. 1, and 2.) is of very substantial brickwork, and, according to the size, from twelve to eighteen feet diameter, rising about three feet above the ground. In the upper portion of this brickwork, from a centre *b*, radiate horizontal flues *c*, opening into another *d* around them, also into the *bags* or vertical flues *e*, and the *mouths* or fire-places *f*. The direction of the radiating flues is exhibited, except at *g*, with the manner of their being partially covered, that through the apertures the heat may readily circulate. The mouths *f* of the common oven are on the outside of the plinth, and in number correspond with the vertical flues or bags *e*, with which they communicate. The size is usually three feet in breadth, two feet in width, and thirty inches in height. The opening *f*, for the reception of fuel in the upper part, resembles a horse-shoe, formed with the coping bricks sloping inward, or with a cast iron coping bond. In the front of each mouth, from the ground to half the height, is another opening or draught hole. *R* is the space occupied by the fuel. The avenue from the mouth to the bags and flues in the plinth is covered at the top with a large fire-brick, forming a bridge or arch, and also a small check hole *k*, that can be covered by a common brick during the baking process. This large brick has a peculiar shape, and is twenty-two inches long, eight broad, and six thick at each end, but about eight at each side of the groove, which is five inches wide. The section is at the height *V V*, in the direction *X X*, dividing the area into two equal portions. The part down to the opening is not given.

The improved oven has the mouths of less dimensions, in shape resembling a *D* reverted, , with a less draught hole, *R*, formed in the plinth, beneath an arched recess of the cylinder *A*. Instead of the check-hole *k*, above the mouth *f*, is fixed in the cylinder an iron frame for a register stove door and catch.

The cylinder *A*, which is the proper cavity of the oven, is of brickwork, about sixteen inches thick, eight to ten feet high, and thirty to forty-five feet circumference. It is erected on the plinth or hearth *M*, which in the common oven is of greater diameter. (The oven used for the baking *glaze* is usually less than for biscuit.) The cylinder is surmounted by a dome *B*, three or four feet high, and in the centre is a circular hole, about two feet in diameter, through which escapes the unappropriated heat, and also the smoke at the commencement. On one side of the cylinder is an entrance, (not exhibited in the

Mechanical
Processes.Baking
biscuit
ware.Description
of furnace,
oven, &c.
Pl. xlix.
Fig. 1, 2.

Manufactures.

drawing,) a large opening through which the oven is filled or emptied, there being steps placed in an inclined plane for easy access. The stopping of this opening is technically called *the clammings* by the fireman. Inside the cylinder are erected, opposite the mouths *f*, the vertical flues or bags *e*, in the common oven about six feet high, and aperture eight by twelve inches. These are much larger in the improved oven, and higher. In different parts of the cylinder are holes, and one in the clammings, through which the fireman can inspect the progress of the baking process, and also draw his trials. To each is fitted a stopper by a luting of clay.

The improved oven is larger and higher than the common oven, therefore it bakes more ware at the same time, (not uncommonly will one hold 1000 dozen, of from six to thirty-six pieces per dozen,) and as the upper part of the cylinder thus approaches near to the wall of the surrounding hovel *m, n*; there is only a little intervening space for the escape of air. The quantity flowing into the hovel is more easily and efficiently appropriated, and the draught being proportionately increased, though the process of baking requires the same duration of time, the quantity of fuel and of labour is diminished.

The whole inside of the oven is constructed of fire-bricks, made of the very refractory clay called *clunch* and *tough tom* by some writers. In Staffordshire it is greyish, coarse, sandy, and strong, alternating with the aluminous ferruginous shale, or with the sandstone bed of the coal measures, and obtained from the bassetings or decomposed portions of the indurated masses beneath them. Its components are silica 60 to 64, alumine 24 to 28, magnesia 4 to 8, and iron 4 to 12. These fire-bricks are laid in a lute of fire-brick clay and sharp sand; and the chief care of the oven-builder is to make every joint in the cylinder so close as to preclude the possibility of any air entering through them into the interior of the oven. The bags are open in their joints, only a sufficiency of luting being used to keep the whole firm in its situation. The first baking will render the whole inside of the oven one compact shell of partially vitrified fire clay.

The outside of the oven is constructed of common bricks, also the outside of the mouths. These, and also the bags and flues, are formed with dimensions of aperture adequate to contain fuel to fully appropriate all the air of the current draught, that, in its circulation through the ample intervals left by the curvilinear figure, elliptical and circular, of the piled seggars, as little as possible of it may escape, and carry away through the hole in the dome a portion of that heat which should be fixed by the baking ware. And, as the expansion during the raised temperature might cause some part of the oven to fail, crack, or bilge out, on the outer edge of the entrance is fixed an iron framework, from which are hooked around the cylinder several strong *tirings* of iron, hoop-wise, at two feet asunder, and also one where the dome commences; and short bars hook into the framework to keep it together and in its place after closing the clammings.

Around each oven, to protect it, and also the fireman, from the action of the atmosphere, is erected a hovel with a square or cylindrical base to the height of seven or eight feet, and then of a conical figure for several yards, as the oven may happen to be for baking biscuit or glaze. To promote the draught, as required in the improved ovens, the aperture at the top of the hovel is

continued in a cylinder *E*, of several feet height. In many hovels for the common ovens, considerable space is left for the passage of a barrow in wheeling the fuel to the mouths *f*, and in the wall *D* are fixed props of wood, higher than the usual height of a man, to bear boards on which are placed new seggars. The hovels for the improved oven are of contracted size, for it is now ascertained (and only very recently has this fact been observed) that this wide space increases much the consumption of fuel by the quantity of cold air constantly ascending and diminishing the draught of the oven.

The seggars are coarse strong vessels, most of them in shape much like a lady's band-box; others are cylindrical, varied in depth from fourteen to eight inches, but the usual size is about twenty-two inches by fifteen. They are made sufficiently thick in the sides and bottom to bear the weight of the vessels placed therein, both before and during the baking process. On the inside of the cylindrical seggars for plates, and some of the others for large dishes, are fixed three strips of the same material, perforated (prior to fixing) with triangular holes, in two rows, alternately of an intermediate height to the other, in which can be inserted *stilts* formed of clay with excess of flint present, to keep the pieces of ware asunder while baking. The marl used in forming the seggars is the grey silicious shale and the carbonaceous schist, both rather gritty, but ductile and very tenacious, found between the strata of coals in all coal fields; both being technically named *marl* to distinguish them from *clay*, the material of the body. The disintegration of the marl is promoted by being exposed to the atmospheric action, or well *weathered*, and passed between strong iron cylinders before it is used. Some very opulent manufacturers regard, as more economical, the practice of working the marl by manual labour upon a suitable plot of land, where it is exposed two or three weeks. The seggar-maker is careful to adapt the proportions of his materials to the nature of the flint or porcelain ware made; and never have these been found defective, unless there has been present some extra dose of alkaline materials unknown to him, and to counteract whose fluxing powers he had not introduced an adequate supply of refractory components. The usual proportions of materials, to render the seggars refractory during the most intense heat of the oven during the baking of the ware; and, while protecting the contained ware from any injury by the carbonaceous particles of the smoke, the sulphur of the fuel, and the direct operation of the flame, remain so adhesive as not to sink under the weight of the ware, and so porous that the atoms of oxygen may permeate the whole during their fixation by the radiation and motion of heat; are grey marl 50, black marl 25, and ground seggars 25; the latter being used to increase the firmness and durability, and an additional dose being added to strengthen the bottom. Seggars thus fabricated will sustain, not only twice or thrice using, (as stated in some Works,) but many repetitions, until injured by accident,—inseparable from so fragile a manufacture.

Before any ware is placed in the seggar, the outside of the bottom is washed with a mixture of litharge 85, flint 15, in water; and the inside likewise with one of these mixtures: *viz.* smelted lime 80, salt 13, potass 7; or, slip 13, cream colour glaze 43, lime 44; or, 40 lead, lime 42, slip 8, Cornish stone 10. Otherwise the edges of the ware would suffer injury.

Over the bottom of each seggar for biscuit baking of

Mechanical Processes.

Manufactures.

flint ware is strewed a thin layer of fine grit sand (from the silicious rocks in the vicinity of the pottery towns), to prevent the pieces of ware touching and adhering. But, for the soft porcelain, which would be liable to *wauve* or alter its shape by baking, there is a necessity for each article to be firmly imbedded in a quantity of dry flint, by which the proper shape is preserved. This is one cause of the very high price of fine pieces of this kind; and will show the great advantage of the hard porcelain of the Middletown Hill kaolin and petuntse. This can be fired plain, similarly to flint ware, without injury to either its firmness or shape, and requires little brushing to prepare it for the glaze. And as the pieces are thus free from the defects of the other kind, so often seen after even the most careful and attentive manipulations, which enhance to the purchaser the price of the perfect, to cover the expense of the defective, there is general advantage to both manufacturer and purchaser.

The seggars, in *setting-in* the oven, are first placed in the spaces between the bags opposite the entrance. On the edge of each is placed a strip of coarse marl, or strong clay, called a *wad*, on which the next superimposed seggar rests, and is imbedded; and thereby should completely close the interior of that beneath, against the entrance of sulphur, smoke, or flame, which would injure the ware during the baking. Their like size, and flat bottom, are thus useful, for each is a cover for that beneath, and then they are piled up in *bungs*, each of some height, or several *rings* of seggars, before another is commenced; while pipe seggars are fixed in different parts, for the more ready circulation of the heat; each *bung*, from the bottom to the top, becomes, during the baking, one compact mass, and the ware is protected against the carburetted hydrogen evolved from the coals. Over the uppermost seggar, when not empty, is placed a (*hiller*) cover, or flat piece of seggar. In succession the bungs are piled up till the oven is completely filled, the bung at the entrance is then placed; the entrance (*clammings*) is then closed with bricks; every crevice is filled and plastered over nearly half an inch thick with mud, to prevent loss of heat.

When the oven is almost filled, the mouths are supplied with a small quantity of burning coals, to which fuel is gradually added, that the baking process may commence very slowly. The fire rests on the ground, in the mouth *f*, and often is heaped up several inches higher than the brick-work; the front aperture is closed with pieces of bricks, between which is ample space for the entrance of a current of air, to promote the combustion of the fuel. Air, however, must always acquire the temperature of 1000° Fahrenheit, before it can support combustion, and its great power at this degree is every day exhibited at the smelting furnaces in the iron districts; consequently, the more quickly this can be obtained, the greater would be the advantage to the baking. Its long contact with the oven, before entering the mouths and flues, is proportionately injurious; and the more it can be previously heated the greater will be its utility. The greatest quantity of heat, from the smallest quantity of fuel, can be obtained only by carefully adjusting the arrangement and direction of the flues to the size and shape of the furnace, and the kind of fuel used. The fuel is cast *upon* the top of the mouths, to regularly supply the fixation of the oxygen, by flowing through the front holes *h*, more efficiently and economically than when cast *in* below. The opinion

that the efficiency of air for combustion results from its density, governed by temperature, a greater supply resulting when this is low than when it is high, is opposed by the facts, that oxygen solely is the source of heat, and is only one-fifth of the volume of the air; while the other four-fifths are nitrogen, and do not in any way promote the heat in combination with the fuel; then, as the air, entering, abstracts from surrounding substances sufficient heat to rise to the temperature of the baking bodies with which it comes in contact and unites, forming some compounds of less specific heat than that of their separate components; some of which, as gas, evolve through the flues and dome, the nitrogen should be prevented carrying off in that manner any portion whatever of the heat. Therefore, while a given quantity of fuel employed at one time will merely produce the heat, not augment its temperature, the introduction of air by some means raised from 60° to 600°, or 1000°, in its passage into the mouths, would as well save all the heat requisite to raise it so high, and greatly increase the intense powers of the fuel. The rapid strides of chemistry towards perfecting manufactures must gratify every friend to improvement; and we may look for great advantages to the Art, from the discoveries in reference to combustion of Rutter, Whitty, Cheverton, and others.

The heat passes along the horizontal flues *c*, and ascends through the apparatus *g* in the hearth, also through the pipe seggars, as well as up the vertical flues or bags *e*, and permeates the whole mass contained in the oven. When there is a deficiency in the supply of oxygen for the interior of the oven, not only is there a very imperfect combustion of the smoke, proportionately limiting the heat, that is so very requisite to be increased; but also, there escape from the hovel immense volumes of inflammable matter only partially burned; and the ware frequently is so discoloured as to require washing in a mixture of nitre and water, and a second baking. The current of heat is more violent through the bags *e*, than the flues *c*, during the general period of baking; but as uniformity of heat is of primary importance, the fireman by properly using the perpendicular check flue *k*, by the brick being either on it, or removed off, he can alter the direction, as well as the force, as requisite, at the bottom or the top of the oven; for by opening this small flue, an additional current of air rushes in, and the heat passes more violently through the horizontal flues *c*. The temperature is very slowly raised for about twelve hours, then regularly urged, according to the nature of the vessels in the oven; and the time required for baking biscuit is from 33 to 40 hours, for porcelain, and 40 to 48 for flint ware; for glaze, 18 to 25, porcelain; 15 to 20 flint ware. A judicious fireman, aware of the contents of his oven, and the coals he is using, will judge tolerably well of the state of the baking merely by inspection, attentive practice enabling him to judge of the degrees of temperature; and he will keep up the high heat its requisite time, and produce excellent ware, often saving in fuel more than the amount paid for his labours. But when the baking devolves on a less experienced or negligent fireman, he too frequently conducts the progress irregularly, and loss ensues; also from *short firing* of pieces, placed in situations deficient in heat; for if the heat be not sufficiently high and long continued, the ware will be very fragile; and if it be too great, or be improperly continued after gaining the requisite high temperature, many

Mechanical Processes.

Manufactures.

of the articles will be fused into a shapeless vitrescent mass. Those bodies which do not flame, when made red hot by continued accession of heat, are without hydrogen, or want power to fix oxygen, so as *per se* to continue the heat. The silicious mass becomes red hot, and continues so by constant heat without producing chemical changes; whereas the fuel, or coaly mass, when hot, evolves hydrogen gas, which, combining with oxygen gas, produces compounds, and feeds its own heat, as long as the hydrogen is evolved and the oxygen is fixed; and then the oxygen, no longer in gaseous motion, by its condensation becomes radiating heat; and the process continues as long as any hydrogen is evolved by the heat of the fixed oxygen, and as any oxygen remains to be fixed.

For the proper management of the baking, a very accurate acquaintance with the appearance and precise duration of the successive rises and degrees of temperature of the interior of the oven, viewed through the small holes in the cylinder, is indispensable to the fireman. He will gradually raise the oven and its contents, from the commencement; adding fuel as the rarefied air circulates and evolves through the dome, the draft increasing till all is at a red heat; increased supplies of fuel raise to a white heat, which is kept up a certain number of hours; and then the mouths are stirred, and charged with fuel, for the *firing-up*, or highest rise of the temperature, to complete the baking, which expelling from the components of flint-ware and soft porcelain all moisture, without fusion, which would render the ware fragile and brittle, the biscuit-ware is so agglutinated as to be properly hard, compact (porcelain semi-transparent) porcelain completely vitrified, and the glaze perfectly vitrescent. He then quickly abstracts all fuel, *draws the mouths*, closes all apertures with bricks, and plasters all joints over with mud or coarse clay; to prevent entirely any loss of heat, as well as any ingress of air along the flues and bags. The oven and all within it are left to cool gradually to a certain degree, and then the entrance is opened; that is, the *clammings are pulled down*; and after a few hours' longer cooling, the seggars are taken out and emptied of their contents. The ware would rift and craze much, was it to be taken out before the whole was down to a low temperature; but this particular is not always regarded in flint-ware manufactories.

There certainly is great need, yet there is no practice of baking by a *pyrometer*; and hitherto, not one has been submitted calculated to indicate correctly the commencement, and precise duration, of the several degrees of temperature, from a red heat to a white, and the continuance of this latter during the baking process. This was attempted by Thomas Massey, Wedgwood's chief fireman, on the principle of the *contraction* of a prism of clay, deduced from that of vessels according to their situation in the oven; and experience rendered him so correct, as never to fail in baking biscuit, glaze, or enamel colours; but no inducement, to his latest moments, could cause him to divulge his secret to any person whatever. His brother, Richard Massey, stated that the prisms were 67 queen's ware, clay slip, and 33 china clay slip, dried in a mould, and formed by the squeezing box; then cut to proper size, made red hot, and adjusted to a gauge. Massey's gauge, now kept by his nephew at Burslem, is a flat piece of well-baked mortar-body ware, about 7 inches by 2 in superficies, and five-eighths thick; in which is a groove 6

inches long, $\frac{5}{8}$ wide at one end, and $\frac{1}{8}$ at the other, and graduated into 180°. The theory seemed plausible; but it has sunk before the fact, that prisms from the same mass of clay have contracted in different degrees in the same heat; and others have not differed, in very different heats and places.

(661.) *Pyrometrical beads*, technically called *trials*, used by the potters' fireman, are made in the form of small hoops, of Egyptian black clay, or of small gallipots, of the common red brick clay found in the neighbourhood. These long experience has shown vary in tint or colour as they contract by the varied degrees of temperature during the baking; and which tints are compared with another properly baked standard trial, to indicate the relative heats. They are placed in a seggar opposite the hole in the cylinder, and are drawn out at different times by a long iron rod. This method is so far useful as it supplies a criterion for the state of the baking at its termination; but it is completely defective in reference to the positive heat of the oven, and the duration of each rise in the temperature.

The *seggar* clay bears the most ardent heat of the oven uninjured, or at any rate without fusing; and, being very cheap, failure is not important. Of this, form a tube of half-inch bore, and 16 inches long, place it near the hottest part of the oven, so that in it, on two or three props of the same substance, may rest a platinum bar, with the inner end against the bottom of the tube, and the other placed to act against the long arm of a compound lever index, constructed with an arc scale graduated to 180°, each equal to 150° Fahrenheit. The platinum bar could be inserted at any period of the baking, and would always indicate the true temperature, as soon as it had acquired that of the oven.

But for utility, accuracy, and convenience, the best pyrometer is one proposed and invented by M. Achard, Berlin, and which may be constructed by any porcelain manufacturer. Of felspar infusible porcelain, by the squeezing box draw out a half-inch bore of tube, and afterwards flatten this a little so as to present an oval figure; to one end of this fix a two-inch bulb, and then bake the instrument at the highest possible heat of the oven. Mix purified metals, (as bismuth 50, tin 30, lead 20,) which will be fluid at 212° Fahrenheit. Put a certain quantity in the ball up to a mark, zero 0°; reduce the temperature to 62°, the intermediate space divide into three degrees, which may be subdivided into 5; and then graduate all the stem upwards, by the same scale, each of which will be equivalent to 50° Fahrenheit, and the subdivisions to 5 each. Of similar infusible porcelain form a strip, the bottom like a cork, to rest on the metal; and a flat stem perforated with a hole corresponding to each 2 degrees. Then, assuming that the metals *expand* agreeably to an immutable law, the heat acting on the metallic alloy will indicate, through the holes of the stem as it rises, as well as through the transparent tube, the temperature of the situation of the ball. Thus will the expansions supply a standard for comparing the heats of the ovens, for biscuit or glaze baking, by the men in charge, under any and every circumstance. Agreeably to these, there is every probability that the annexed will be the numbers for the several results; (biscuit and glaze bakings;) the temperature at which mercury boils = 13°; zinc 14, antimony (the red heat, of daylight) 19, burnishing gold 32, silver 36, enamel colours 37, lustre 40, copper 44, gold 50, delft ware 108, and 103, iron welds 130,

Mechanical Processes.

Pyrometrical beads.

Manufac-
tures.

cast iron melts 174, manganese 210, nickel, and malleable iron 229, platinum 231, cream colour 245, 240, flint ware, printed, 250, 244, bone porcelain 255, 250, Worcester 266, 300, stone ware 286, 280, chemical utensils 290, Chelsea porcelain 294, 290, Derby 313, 300, common Canton 333, Bow china 336, 330, Bristol 373, 366, felspar porcelain 420, 400, Japan porcelain 427.

The only difficulty (and it is one) is the liability of the above given compound to dissipate by the high heat. Gold would not do so.

Dipping
and baking
glazed
ware.

(662.) *Dipping and baking glazed ware.*—When the biscuit oven is *drawn*, the ware is carefully lifted from the seggars into baskets, and carried into the sorting room or biscuit warehouse, where each article is examined, and tried by its *sound*, whether fit for further processes; and then it is put aside till wanted. Each cracked vessel is consigned to the sherd-heap (*shord-ruck*.) Biscuit porcelain has great resemblance to fine statuary white marble, without lustre on its surface; and the figures and vases formed thereof, at the continental and English factories, have beauty and elegance in accordance with the quality of the components to properly exhibit the elegance of the workmanship, preserving all the edges and lines sharp and clear, like to fine sculpture, not possible to be attained in glazed ware.

The very coarse ware, usually with a *black* or *brown* opaque glaze, is only once baked; the vessels in the clay state being coated with the fluid mixture of lead ore and manganese, in water; or black oxide of manganese and galena are pulverized, and put into a coarse linen bag, which allows the particles to pass through in dust on the surface of the ware. The fluid mixture is poured into the vessels, quickly thrown around by a dexterous movement of the hands, and then poured out. The vessel thus coated is placed to dry, and the whole becomes one compact mass by baking. Small porringers, thus made, must not be used for any kind of *sour* or acidulous liquids, as the lead glaze is thereby destroyed; and the metal, dissolved in the liquid, if taken into the stomach, will be very deleterious.

Salt glaz-
ing.

(663.) *Salt glazing* is practised chiefly at the manufactories at Lambeth, Chesterfield, and Belper. The sides of the seggars have several holes in them; and when the ware is at that degree of heat requisite to dissipate all the water of the alumine, a mixture of 98 common salt, and 2 deutoxide of lead, is cast in small quantities into the oven, through square holes above the bags; and the additional heat thus obtained, and alkali supplied, promotes the fusion of the silica on the surface, and thereby covers the vessels with a vitreous coating, coloured a little by the iron in the earths used. When the practice prevailed in Staffordshire, at the time of casting in the salt, a dense white vapour arose, which enveloped the district so completely, as to equal the most dense fog of November known in London; and many ludicrous occurrences are yet remembered, and commented on by the septuagenarians.

The process of *washing* the vessels (in the clay state, but moderately dry) with a mixture of components vitrifiable by a moderate heat, as the ware was being baked, was the first to supersede the use of salt in glaze. The great inconvenience of this process was not long in suggesting a different and efficient method of applying the glaze. The clay ware will neither bear washing nor dipping, in the fluid mixture of vitrescent components; for the water is so quickly absorbed by the alumine, that

the vessels become soft, and by bilging or sinking, irreparably alter in shape or figure; and even if these defects did not ensue, the clay state is too fragile to sustain the manipulations of the ornamental department, painting, and transferring the impressions taken off engraved copper-plates. The biscuit-baking process is therefore indispensable to adapt the ware to sustain these uninjured.

Even when the ware has been baked biscuit, its dry appearance will suggest, and its bibulous nature, from the presence of alumine, on immersion in water, will demonstrate its porosity, inconvenient, for many purposes of utility, and occasioning rapid decomposition. This inconvenience has been understood by all manufacturers of earthen vessels; and the necessity as well as utility of a preservative covering, led to the employment of a glaze applied to the biscuit ware. It was requisite that its bibulous and permeable nature should imbibe the water of the mixture readily, and leave the surface covered with a thin coating of components, readily drying into a solid shell of uniform thickness over all the parts, sufficiently hard not to be rubbed off, but remain permanent, while the vessels are being placed in seggars, kept asunder by cockspurs, stilts, triangles, &c. while again exposed to the *glaze-baking* process, at a white heat, for many hours continued, of all inside the oven, bags, seggars and their contents, by which the components during fusion incorporate with the surface; and at the completion of the process, that the ware should be covered with perfect glass, promoting the durability, and improving the appearance.

The components of the glaze are mixed, either, as *raw*, when they are not fritted together and pulverized prior to grinding; or as *fritt*, when previously brought by heat into chemical combination. The glaze is ground in a vat into a semi-fluid; and when other components have to be added, as white lead, to mix these is used a small hand-mill, (fig. 6.) formed of a strong hooped vessel A, in which works a vertical shaft B, on which are fitted four strong gate-like frames C; the top has a strong iron bevel wheel D, which works into another on an iron shaft that passes over the top of the tub, and has on one end a fly wheel E, four feet diameter, and on the other a winch F, for the workman to turn. From this mixing tub, the semi-fluid (as thin in consistence as is possible conformably to the contractile nature of the body, and proper combination in baking) is put into a dipping tub; and, to render the water more buoyant when using metallic oxides,—whose superior specific gravity causes them constantly to tend to precipitation and continuance at rest at the bottom of the tub; but which should be suspended in the fluid, that the ware may not be immersed in a semi-fluid, in which scarcely any components of glaze are present,—there is used a *flow*; a dose of either common salt, (chloride of sodium,) disregarding the yellowish tint that results from the reaction of the chlorine and the metal, or of muriatic acid, which is prejudicial, because while being dissipated by the high heat of the glaze-baking, away with it goes whatever it held in combination.

Dipping is the technical name of the process of covering the vessels with the substance which by baking forms the *glaze* of the ware. The articles in the biscuit state are carefully brushed from dust, and porcelain from the flint; then the *dipper* receives each large vessel, which he immerses in the glaze tub, lifts it out, and by an adroitness not describable, and incon-

Mechanical
Processes.

Manufac-
tures.

ceivable by persons who have not witnessed the manipulation, he rapidly gives to the article different positions, in order that the covering may be uniform, and the glaze, when baked, may not be thicker in one part than in another; and during the change of position, the water in the mixture is absorbed by the vessel, which is then placed upon a hair sieve, or a board in which are rows of nails with the points upwards, for the superfluous portion of the fluid to drain off. When sufficiently dry to bear moving, the several articles are again placed in seggars to sustain the gloss or glaze-baking.

There is scarcely need for the remark, that the fusion of the components of the glaze by cooling would cause the vessels to adhere, if they had been placed together. To prevent this, by keeping them asunder, and also to present opportunity for the oxygen fixed by the supply of fuel properly to affect the surface of all the ware, between the pieces are placed small separators, named *stilts, triangles, cockspurs, rings, and pegs*. These are formed of clay which contains an excess of flint; and very often the fine points of these are so imbedded in the glaze, that they are fixed therein when cold; and to separate them, they must be broken, rendering the instrument itself useless in future processes, and leaving a mark on the ware, which is disagreeable to the eye, and causes the trouble of dressing which endangers the article itself. Efficiently to remedy this great disadvantage, the following hint is given. Let some fine platinum wire be cut into lengths of one quarter of an inch; and in each point of the cockspur, or triangle, let one of them be fixed while in the clay state, and baking will render it immovable; its fineness will preclude more than a mere speck from being visible; and the cockspur, &c. may be repeatedly used without sustaining any injury.

The frequent expansion and contraction of the brick-work of the oven, and especially the sudden cooling, expediting its destruction, the manufacturer finds it his interest, not only to allow the cooling to take place very gradually, but also to keep up such a stock of ware from his workmen as will allow the seggars to be again filled therein as soon as the oven is sufficiently cool.

Ornamental Manipulations, Components, Proportions, and Processes of Colours, for Blue Painting, Blue and Black Printing, Enamelling, and Lustres.

Ornament-
al manipu-
lations.

(664.) The modern improvements in the embellishing of porcelain and pottery, did not originate with our native potters; for specimens yet remain to prove, that the ware called *faïence*, covered with the glaze of Palissy, agreeably to the processes of Petitot, had been occasionally honoured with the efforts of some of the greatest masters of the art of design. Works on porcelain are extant said to be from the hand of Raffaele and of other eminent painters, and the cabinets of the curious present specimens of British porcelain, with designs executed by our very deservedly celebrated Countryman, Sir John Thornhill.

Solution of gold.—1. In 33 parts of nitric acid, with specific gravity 1.350, and 77 of muriatic acid, of the specific gravity 1.144, at 80° Fahrenheit, dissolve small doses of grain gold till the liquid is saturated.—*Another method*, less efficient, is,

2. In 50 parts of pure water, 33 nitric acid 1.350, and 17 muriatic acid 1.144, at 100° Fahrenheit, dissolve doses of grain gold to saturation; then add 6 parts of nitric solution of silver.

Were these concentrated solutions to be mixed, the result would be a very acidulous precipitate of metallic gold.

Solution of tin.—1. In 77 parts of muriatic acid, of the specific gravity 1.144, at 112° Fahrenheit, dissolve 33 parts of grain tin in doses of 4 or 5 parts at each immersion; and always in day-light, to preclude danger from the evolved hydrogen exploding by a lighted candle coming in contact. The solution thus formed will be clear, and incapable of being rendered curdle or coagulate.—*Another method* is,

2. In 76 parts of nitric acid, and 34 of muriatic acid, (or in nitric acid saturated with common salt, or with muriate of ammonia,) at 112° Fahrenheit, dissolve small doses of grain tin till saturated.

The solution of tin (1.) has the metal in the state of proto-muriate, or *that only* which is proper to be a component of the *purple* for potters' use. Other preparations of gold will form a fine purple, without the presence of tin; and therefore the tin is not indispensable, as it has very slight colouring power; but it is used because of its peculiar property of rendering the purple, of which it is one component, more capable of sustaining the continued high heat of the oven requisite for it to become properly amalgamated with the softened glaze; and it also renders the gold refractory in very high heats, and the proper state of oxidation is preserved by the flux. The solution of tin (2.) has the metal in the state of a hydrated per-muriate, and, from using it in the precipitation of the purple, not only have there been unnumbered disastrous and vexatious results in the processes, but most expensive failures when the work was baked.

The purple colour for potters' use.—To 80 parts of gold solution, (1.) 20 parts of tin solution, (1.) and 1 part of nitric solution of silver, add respectively of pure water at 200° Fahrenheit, 800, 200, and 10 parts. First, mix well the solutions of gold and silver; then stir very carefully with the feather of a strong quill while gradually pouring in the solution of tin; and as the precipitate forms, constantly stir in more boiling water until no more appears, then leave the whole to rest 24 hours or more. Adding carbonate of potass will recover the acids as nitre.

The assertion has been made (but it is not clear how the fact is possible) that, in combining these very dilute solutions, every 1 of gold will produce 5½ of purple. Does the remark regard the combination with a flux? If so, the colouring power of the above purple being to flint glass as 1000 to 1, the results will be much greater; the proportions may be, for mixing, purple 4, or 3, with 96 or 97 of flux, (red lead 76 and ground glass 24, or white lead 58, calcined borax 30, and flint glass 12,) or, purple 15, red lead flux just mentioned 75, white oxide of antimony 10.

Another method, very tedious, is: immerse a plate of grain tin 2 hours in the gold solution; then with a feather clean off the purple; repeat the immersion till no more purple be formed; again saturate the solvent with gold for another course; and when all is abstracted carefully, dry the purple powder.

Some persons use in solution, gold 47, tin 47, silver 6, and the precipitate they flux with borax 53, red lead 37, and ground flint 10.

A purple without gold is formed of manganese 45 parts, red lead 50, cobalt calc 5.

Mechanical
Processes.

Manufactures.

Purple.—Gold 1, flux 3.—Flux red lead 8, glass 7; or, borax 5, flint-glass 16, red lead 5.

Purple lilac.—Pulverize together, and then fuse, manganese 34, best smalts 76.

Purple, (under glaze.)—Fuse together 2 hours, manganese 46, red lead 46, cobalt calc 8.

Purple distance, (enamel.) Mix together enamel purple 12, manganese, oxide of, 18, flux 70, (red lead 25, ground glass 75,) or, gold purple 46, manganese 6, and flux 48, (glass 77, red lead 23.)

Rose colour.—In pure water 95, heated to 190°, mix gold solution 5, add sal ammoniac till no more precipitate appears, then let the liquid remain at rest, at the shortest, 24 hours. By siphon draw off the liquid; and, unless wanted immediately, very carefully wash in great excess of boiling water; and as the precipitate is dangerously fulminative, because the acid is peculiarly affected by the volatile alkali, a plaster slab is best, for many reasons, to receive it to dry, and from which it is brushed with a feather.

For many uses, the precipitate is formed by adding carbonate of potass; and the acid being neutralized by the vegetable alkali in chemical combination, the precipitate is not fulminative, though equal to the preceding.

Keep very cool, and, with a feather, mix, of the precipitate, 3 parts, chloride of silver, 1 part, and 96 of flux, (17 red lead, 50 ground flint, 30 borax.) Or, purple precipitate 3, silver 1, flux 96.

The oxides of iron supply the palette with several different shades of enamel colours, *rose, red, and brown*, changeless, when properly prepared, on either kind of porcelain; and varied in tint by the degree of heat to which the oxide is first exposed. Certainly they are less brilliant than those which have gold for their base; but they are very beautiful, and, on a glaze of Middletown Hill petuntse, peculiarly fine and rich; even on one of artificial felspar they are preferred, because more certain in their application, and improving in brilliance, by baking, when combined with a proper flux. When excess of lead is present in the glaze, the colour suffers in tint to a dull disagreeable hue. The *red* is regarded as resulting from imperfect vitrification, which keeps the particles of the peroxides suspended in the mass; and by mixing varied proportions of the red and the black oxides, are formed the different shades of red, brown, chestnut, chocolate, &c.

The *red* is usually a nitrate of iron, afterwards carefully calcined; and, by raising the heat, brought to *dark red* and brown. In nitric acid dissolve iron filings; with pure rain water dilute; to precipitate the oxide, add bicarbonate of potass, or tartar, whose carbon will aid to dissipate the hydrogen, and alkali will promote the calcination of the precipitate, placed on a sheet of iron, exposed to a clear fire till the powder is a fine red. Grind for use colour 25, flux 75, (of borax 23, red lead 41, ground glass 36; first fritted.) Or,

Calcine some pure table salt; then take of this calc 66, and 34 of the preceding colour; mix well together, carefully calcine, not fuse; pulverize the calc; with boiling water abstract all the colouring particles, which must be left to completely subside; then by a siphon draw off all the clean water; wash the sediment frequently with pure water; and for *rose*, colour 25, flux (above) 75. Or,

Calcine good copperas in an open fire, that only may

remain the powdered peroxide of iron; (which should be bright red, or fine orange, not brown, or cream white, easily formed by excess of heat;) with boiling water, five or six times wash out the sulphuric acid, and dry the powder.

Enamel red.—Calc 25, flux 75, (above,) or, 30 and 70.

Light red.—Calc 30, flux 30, ceruse 40.

Dark red.—Colcothar 20, flux 80, or, 25 and 75.

Pink, (for printing.)—Concentrated muriatic (1.144) acid, saturate with oxide of chrome; and in other muriatic acid dissolve pure tin; to each solution 10, add pure water 90, at 212°; filter; mix well the solutions, and add boiling water till all precipitate is down. Dry colour 25, flux 75. Or, fuse together oxide of chrome 30, oxide of tin 70; or 40 and 60.

Flesh red.—Muriatic acid concentrated, saturate with best black oxide of manganese, then to solution add nine times the quantity of boiling pure water, immediately filter, and evaporate; then in a cool place crystallize. The crystals grind, 50 parts to 50 flux, petuntse 75, potass 25.

Or, (for *filled-up* patterns,) in two quarts of pure rain water, for three hours, simmer or slowly boil, 28 ounces of clean sulphate of iron, and 8 ounces of gum Arabic; reduce to 1 pint, cool, and bottle for use.

The *brown red* colours, from mixing varied proportions of the black oxide of manganese and the brown oxides of copper and of iron, (when fritted with the flux previous to grinding in the mill,) remain unchanged by the baking heat; because the oxide of manganese prevents the lead of the glaze affecting the oxide of iron. The *brown red* ground (French *fonds caille*) is colour 25, best petuntse 75. The russet and tortoiseshell grounds are colour 34, flux (see flesh red) 66; colour 25, umber 25, flux 50.

Purple brown.—Peroxide of iron (red nitrate) 15, flux 85, (petuntse 75, alkali 25.) Or, colour 20, flux 80.

Red brown.—Fritt manganese 64, (or 62,) white lead 12, flint glass 6, (or 7,) flint 12, and borax 6 (or 7.) Fawn red (above) 50, terra sienna 50; grind for use.

Red brown (light.)—Contents of retort, after abstracting oxygen from manganese, 50, and petuntse flux (above) 50. Grind for use. Or, peroxide of manganese 66, oxalate of potass 34, mix well in hot water; filter, add ammonia, the precipitate dry, and grind colour 50, petuntse flux 50.

Mulberry (under glaze.)—Pulverize and mix manganese 54, blue calc 20, borax 12, place on a biscuit dish, and cover with 14 of pulverized nitre; carefully calcine and grind, colour 50, flux 50, (flint 40, ground glass 40, red lead 20.)

Brown (for enamel.) Dark.—Brown oxide of iron 34, flux 66, petuntse 80, potass 20.

Light.—Red oxide of iron 12, yellow (under glaze) 9, calcined umber 9, and flux (above) 70.

Brown (for under glaze.)—Glass of antimony 40, litharge 40, manganese 16, blue calc 4. Or, crude antimony 26, litharge 66, manganese 15, blue calc 3. Or, litharge 48, 28, crude antimony 18, 14, glass of antimony 18, 0, oxide of manganese 13, 14, zaffre 3, 43, blue calc 0, 1. Or, (for *lines*.) 21, 0 49, 16, 0, 7, and nitre 7. Or, 50, 16, 14, 14, 0, 4, colour 50, flux 50.

Brown (for printing.)—Litharge 33, 37, antimony 27, 37, manganese 27, 18, blue calc 13, 8.

Mechanical Processes.

Manufac-
tures.

For *topping*.—Brown (above) 50, 40, orange 16, 8, white lead 8, 20, glass 28, 32. Fritt together.

French brown.—Orange 50, umber 25, flux 25, (red lead 28, glass 65, borax 71.)

Chestnut brown.—Red (above) 25, French brown 75. Grind for use.

The *blue colours* are supplied by the oxide of cobalt, whose tendency to alumine renders them the most rich, fine, solid, and fixed whatever heat may be applied, of all colours on porcelain or flint ware. The pure oxide is used for the very rich and beautiful tints; and for the others, various combinations of the oxides of cobalt, tin, and zinc. But much of the brilliance is dependent on the components of the body, or the glaze, as well as the variety of shades. The alkalis give a deep blue precipitate; fusion with antimony and litharge forms a green; and fusion with manganese and iron a black. The alkaline earths, barytes, lime, and magnesia, affect the cobalt, when sulphuric acid is present, and injure or destroy the printed patterns.

The oxide of cobalt should be completely free from arsenic, to prevent the radiation of the metal by its combination with the alumine of the body resembling smeared writing, and injuring the lines, which should be clear and distinct; or giving a bluish tint to white glazed ware baked at the same time in the same seggar with blue painted or printed. Brongniart first announced this remarkable effect. And also, but without giving the process, that from pure chromate of lead he had obtained a deep fixed blue for porcelain. Yet he has blamed his predecessors for the very same conduct!

Blue.—Pulverize cobalt ore, and well mix. Ore 40, carbonate of potass 40, Lynn sand 14, charcoal 6. Or, cobalt ore 25, zaffre 25, potass 35, sand 10, charcoal 5. In crucibles that contain about 3 pints, put $1\frac{1}{2}$ pound of mixed materials; place these in a muffle connected with a reverberatory furnace; gradually raise the heat for seven hours, then regularly diminish for nine hours longer. When cool, the upper substance will be cobalt and a silicate of potass; and below will be nickel and bismuth. Then pulverize the silicate, and the powder put

In small pint flanced biscuit jars, calc 90, potass 10, about 1 pound in each crucible; raise the heat six hours, and diminish 7; repeat this till the silicate be very pale in colour. Pulverize this calc also. Next,

On biscuit dishes strew ground flint one quarter of an inch thick; on which spread the last calc, and carefully calcine well six hours, to dissipate the arsenic, (which will remain if the calc be *fused*), and separate the nickel. Pulverize the blue calc; and

Mix well, calc 90, best flint 6, borax 4; or 85, 9, and 6 potass.

In a similar way mix like quantities of zaffre and the alkalis, to form a coarser blue.

In earthen cups, half an inch thick, 3 inches diameter, and $1\frac{1}{2}$ high, put of the powder, and place in the muffle; raise the heat 6 hours, and diminish 7; the top will be blue calc, the bottom nickel, and other metallic scoria.

When a quantity of nickel is accumulated, pulverize and mix, metal 80, plaster 12, borax 8, put in cups and fuse 16 hours. The blue thus obtained is usually mixed with the zaffre blue.

Strong (for printing).—Blue calc 40, flux 60. (Petuntse 80, potass 20; or, red lead 18, flint 36, glass 28,

nitre 9, borax 9.) Or, calc 35, 30, and flux 65, 70; or, calc 20, flux 40, and 40 white lead. Or, calc 25, and 35 flint, or barytes.

Weak, (*Broseley*).—Blue calc 20, flux 80. (Flint 70, nitre 9, borax 21;) or, calc 15, petuntse 85.

Blue (for painting or enamel).—Blue calc 25, flux 75, (flint 14, glass 28, white lead 35, nitre 23;) or, 30, 70. (For grounds,) blue calc 45, petuntse flux 55; or, 35, and 65 for Wellington blue. Or, fuse smalts, azure blue, grind, and mix calc 25, flux 75.

For smalts, (for printing glaze,) fuse together cobalt calc 10, borax 30, glass 60; or, zaffre 20, potass 20, flint 60.

Sky blue.—Fuse together two hours, copper filings 10, soda 40, flint 50.

One of these fritts is occasionally added. Zaffre 20, black flux 80, smalts 12, soda 88, oxide of cobalt 26, glass 54, coal 20.

Cobalt ores are found in several places in England; yet, although there is so great a demand for the calc weekly, they are not collected. A few years ago, a Company for this purpose was formed, and their produce sold at the average price of 47s. 6d. per pound; but the prejudices of the potters, and the want of chemical knowledge, neglect, or how to produce *matt blue* (pure calc) from the refuse scoria, rendered the concern unprofitable; and zaffres continue in demand for the preparation of the colour.

The *yellow colours*.—Before modern chemical research for cheap and facile processes supplied means for readily and cheaply obtaining chromic acid, the enamel yellows were formed of varied proportions of oxides of lead, silver, and antimony; and required very careful management of the processes, to prevent the lead losing its oxygen, and causing black specks.

Upon glazed flat dishes spread iron filings; sprinkle with water to oxidize them; wash off the oxide, and again sprinkle; when the oxide has settled, by siphon draw off the water; dry the oxide, and in a covered crucible calcine at a moderate heat, from 4 to 8 hours, according as the tint is required to be brighter or darker. Colour 40, flux 60.

Yellow calc.—Litharge 17, 48, antimony 17, 36, lead ashes 33, 0, oxide of tin 33, 16.

Base yellow.—Pulverize, mix, and fritt white lead 40, tin ash 40, litharge 10, antimony 10.

Yellow.—Fritt red lead 80, antimony 10, oxide of tin 10, colour 40, flux 60.

Orange (enamel).—Fritt red lead 60, antimony 20, flint 15, red oxide of iron 5; for use grind together, colour 28, flux 72. Or, Naples yellow 35, flux 65.

Orange (under glaze).—Mix and fritt, litharge 46, 55, antimony 30, 32, oxide of tin 8, 0, brown oxide of iron 16, 13. Grind for use.

Naples yellow (fine gold).—Mix well together, and carefully stir while calcining for not less than three hours, white lead 75, 70, 76. Antimony 11, 20, 16, alum 4, 5, 4, and sal ammoniac 7, 5, 4. Colour, Naples yellow 30, flux 70.

Chrome yellow, the most brilliant colour; an insoluble compound of a metallic acid and a metallic oxide, more beautiful and durable than any of the ancient yellows, and much superior to compounds of oxides only; as, when red oxide of iron is employed to heighten the tint, its colouring power suffers under fusion with lead.

Mechanical
Processes.

Manufac-
tures.

Nitric acid saturate with lead, to solution 10, add pure water 90; then add solution of chromate of potass till all the metal is precipitated; let the liquid stand 24 hours; draw off the water, dry the precipitate, and mix for use. Colour 50, flux 50. Or,

One pint of pure water saturate with acetate of lead, add 16 ounces of ground carbon of barytes; boil, and add half an ounce of chromate of potass. Settle 24 hours; draw off the water, and dry, for use.

Nasturtium.—Chrome yellow 24, flux 76.—(Fritt, separately, glass 10, 3, lead 3, 2.)

Straw colour.—Oxides of lead and uranium 50, and 50, grind together. That of titanium supplies a pale dull yellow ground.

The *green colours*, from oxide of copper, or yellow and blue mixed, to prevent them assuming a black tint are fritted with their flux prior to grinding; and, thus prepared, they remain uninjured by very high heats.

To a saturated solution of acetate of copper, add carbonate of potass, and keep the quick precipitate separate from the sluggish; the former supplies a brilliant fine green; the latter one olive, dull, and earthy. Other shades are obtained by similarly treating saturated solutions of muriate and arsenite of copper.

Olive green (for grounds).—Fritt flux 50, blue calc 20, oxide of nickel 30; or, chrome yellow 30, carbon of barytes 8, damp blue 60.

Blue green (enamel).—Very carefully fritt. Red lead 40, 50, glass 12, 0, flint 14, 18, borax 9, 16, copper calc 7, 8, yellow calc 5, 8, white enamel, 10, 8. Or, for

Yellow green—40, 12, 14, 4, 9, 10, 11. Or, blue green fritt 88, enamel yellow 12. Or, white lead 42, flint 12, borax 22, glass 9, base yellow 12, copper 3.

Grass green.—Blue green fritt 77, enamel yellow 23.

Fritt oxide of nickel 80, nitre 20, supplies the brilliant emerald green of the Sevres porcelain, and will bear uninjured any degree of heat.

Green (under glaze).—Biscuit yellow 87, blue calc 13. Or, yellow calc 60, blue calc 8, white enamel 20, flux 12.

For edging, (under glaze,) enamel blue 10, oxide of tin 15, flint 20, glass 30, copper calc 25, colour 50, glaze 50.

Celeste blue green.—Chrome yellow 20, 25, 30, Prussian blue 80, 75, 70. This is best on a petuntse glaze; on others there is deficiency of brilliance.

Oxide of chrome, which sustains any heat without injury, is now very generally used in the manufacture for a *green*.

In concentrated muriatic acid dissolve, till saturated, oxide of chrome; to solution 10, add 90 pure water at 212°; filter, evaporate, crystallize, and calcine the crystals. Colour 50, flux 50.

Or, chrome yellow 80, arsenic 10, potass 10. Arsenic is not desirable.

The *black colours*, alike beautiful and excellent, are formed with difficulty, because no metallic oxide, *per se*, is really black; platinum gives the best, manganese the next, and that from iron is opaque, dull, blistering, and easily becomes reddish. The general practice regards the compounding chemically the oxides of manganese, cobalt, and brown of copper; and when used with a petuntse flux, or on a petuntse glaze, the colour

is brilliant; but on other glazes, much attention is requisite to prevent the colour scaling off and becoming dull.

Black (for enamel).—Fritt, borax 32, calcined umber, best, 16, red lead 20, enamel blue 16, flint 8, blue calc 8, colour 25, flux 75; or, oxide of manganese 8, iron 8, copper 8, cobalt calc 8, glass 52, nitre 16; or cobalt calc 30, umber 36, oxide of copper 34. Or,

Muriate platinum dilute with pure water, add dilute solution of nitrate of mercury; by a clear fire volatilize the mercury from the precipitate, and use colour 25, flux 75, glass 90, nitre 10.

(For *black printing*.)—Of the first above 80, enamel blue 10, enamel purple 10; grind for use. Truly excellent and brilliant for landscapes and flowers on a petuntse glaze. Or, calcined borax 46, calcined umber 36, blue calc 18. Or, 15, 57, 12, and 16 red lead. Or, oxides of cobalt 66, nickel 34.

(For *printing*.)—Fritt. Red lead 60, antimony 25, manganese 15; then add blue calc 40, oxide of tin 5, and grind for use. The cobalt has the same tendency to strike manganese *black* as alumine *blue*.

(For *lines*.)—Copper calc 25, flux 75. Or, 30 and 70. Or, 40 and 60.

The beautiful *black* on the Sevres porcelain, which, because of its petuntse flux and on a petuntse glaze, will sustain the highest heat, is cobalt calc 26, black oxides of iron 36, and of manganese 38.

The *pure white colour* is obtained by rather an operose process. In distilled water dissolve 1 pound (or more *ad libitum*) of good table salt; filter, evaporate, and decrepitate; or filter, partially evaporate, crystallize, and use the cubical crystals. In a fire place a covered crucible, and when red put in a certain weight of block tin, with which, when red-hot, mix well twice the weight of the preceding salt; cover very closely, often stir with a clean red hot spatula; and when its end becomes white, from 60 to 80 minutes, the calc is ready for the next process. Pulverize and pick very clean the calc; again put it in a covered crucible, and raise the heat three hours; when cool wash away all the salt left; boil the residue violently two hours; decant, let the solution rest twenty-four hours, and draw off the water. Colour grind for use.

Chloride of silver.—In concentrated muriatic acid 25, diluted with pure water 75, at 212°, dissolve silver till saturated; then add for 10 solution 90 water at 212°. With common salt, well stirred in, precipitate the metal as chloride of silver; let the whole rest two hours, draw off the liquor, and wash the precipitate until quite insipid. This is a component of the best yellow colours of the early hard porcelain, and of the yellow stain for glass.

Silver (for *burnishing*, or *black Egyptian*).—In concentrated nitric acid in a sand bath dissolve 32 grains of silver, then add to solution 8, water 92 at 190°; insert a plate of polished copper twelve hours, decant the water or filter, wash well the precipitate, and dry for use. By iron filings precipitate the copper as a rich and fine *bronze*. Grind for use ceruse 20, silver 80.

Gold (for *burnishing*.)—To solution of gold 75, and muriate of silver 25, water at 212°, 900; add a saturated solution of proto-sulphate of iron; as long as there is any precipitate stir well together, and let the whole

Mechanical
Processes.

Manufac-
tures.

rest twenty-four hours; decant the liquid, wash the precipitate well, dry, and use with nitre or borax as flux. Or, to solution of gold 77, ditto silicate of potass 33, add muriatic acid till precipitation ceases; wash and dry for use; metal 6, flux 94. Or, gold 80, silver 13, oxide of bismuth 7; grind, metal 26, flux 74. Or, gold 66, mercury 34; then metal 20, black flux 80, of 33 nitre, and 67 bitartrate of potass. Or,

The solution of gold, evaporate dry; well wash in great excess of pure water, gently heat to 130° , gradually add a solution of caustic potass till all the gold precipitates of an orange tint; let it settle twenty-four hours; by siphon draw off the water, and then evaporate the precipitate. The gold must not be dropped into the potass, else it will become blackish-brown, because of the alkaline nature of the menstruum, and the acidulous property of the gold. The gold is used for some purposes, with a certain proportion of flux, to fuse with the glaze of the ware. The proper management of the gold in these processes, to secure that state of peculiar comminution in which it can be used to the best effect with economy, requires great attention, and must provide antidotes for injury from excess of heat, hydrogen, or carbonaceous vapours. The weekly consumption of gold in Stoke-upon-Trent Borough is about £650 sterling, or £35,000 per annum.

The colour-mill is a strong box, in which is fixed a block of chert or quartz, hollowed like a shallow bowl; in this fits a smaller block, with the under surface to fit to the bowl, and the upper perforated for the square end of an upright shaft to rest in and move this block. The calc and flux are thus ground together in water for about six hours.

After the colour has been ground at the mill it is usually dried well, and is next put on a very smooth and hard stone, and with a muller ground in water or oil as proper, until it is free from the least perceptible roughness, either under the muller or between the fingers.

Blue Painting.

Blue
painting.

(665.) The earliest method of ornamenting flint ware, table plates, &c. was by colouring the grass-work on the edge of the flanch green by oxide of copper, or blue by that of cobalt. Neither this nor the painted border required or exhibited much taste in the pattern or ability in the execution. Subsequently, these were superseded by lines of blue or brown, formed as the plate was in motion on a whirler, (described in the Enamelling Manipulations,) and ware thus traced is called brown line ware.

This method of ornamenting common flint ware is adopted for patterns most in demand by the labouring classes. At first these patterns were very rude imitations of the uncouth and unmeaning designs and figures seen on old blue porcelain; and in both originals and copies truth was outraged and taste disregarded. A better style was adopted by Wedgwood, who excited attention to finer compositions, and to correct taste, by rejecting those patterns and substituting copies of drawings of British plants and flowers on his tea services. Young women trace them with camel hair pencils on the surface, and have to exercise considerable care, because every stroke of the pencil remains permanent on the ware, and cannot be erased as in enamelling.

The colours are ground in water, and worked with a little gum or sugar rubbed on the palette. Mechanical Processes.

Flint-ware in the biscuit is now ornamented by either the pencil or by a great variety of elegant patterns neatly engraved on copper plates, from which impressions taken on paper are transferred to the surface of the vessels, and blue being the colour first used, these manipulations are named blue painting and blue printing. For several years only two patterns were used in printing; the willow for table ware, and the Broseley for teas. But latterly numerous others have been introduced.

Blue Printing.

(666.) The printing press used for this purpose consists of two iron cheeks, five feet high, one foot broad, one inch thick, strengthened in the parts where strength is required. These stand vertically on the plinth or foot, fixed by screws about two feet distant, kept asunder and firm by a bar below and the head-piece above. Each cheek has two apertures for brass steps for the axles of the two iron rollers, preserved at a proper distance and secured by stout screws. The iron rollers are about 22 inches long, 1 thick, and 30 in circumference, with three folds of blanket almost round the upper fastened by cords. The axle of the upper has one end passing to the outside of the cheek with a square end for fixing a lever to turn the roller, rather more than the plate is in size, and, by the motion, turns the lower roller, so as to draw in or expel the plank or iron plate about 1 inch thick, and 28 by 22 inches surface.

The press is placed for convenience very near a stove of thick iron plate. On this stove the printer places his copper-plate, while he rubs the colour into its lines by a leathern rubber rolled and firmly tied together. The metallic calc which forms the colour in the requisite proportion is well ground with an oil on a very hot plate. The oil is often prepared according to the humour and whim of some self-consequential workman; but we have never heard of the following being inefficient. In a covered jug over a slow fire for two hours boil 1 quart of pure linseed oil, and when the oil is not pure but throws up a scum, carefully take it off; (some printers at this stage put in gradually 2 ounces of red lead, and burn off the greasy particles;) add 1 pint of best rape oil and 2 ounces of copaiba balsam, boil slowly two hours longer, cool to 160° , and add half an ounce each of amber oil, white lead, and clean pitch; again raise the heat to 212° , and continue it 45 to 75 minutes for weak to strong tints: or, linseed oil 1 quart, rape one quarter of a pint, copaiba balsam 1 ounce, tar one quarter of a pint, and balsam of sulphur carefully introduced to prevent the whole coagulating; or, 1 quart linseed oil, 4 ounces of the flowers of sulphur, 2 ounces of rosin, 4 ounces of balsam of sulphur; or, linseed oil 1 quart, red lead 2 ounces, Barbadoes tar 4 ounces, balsam of sulphur 4 ounces, and half an ounce each of rosin, acetate of lead, oil of amber, and copaiba balsam.

While the printer rubs in the oil (or colour) the plate becomes so hot as to render the use of thick pieces of leather indispensable on the thumb and fore finger of the left hand. The oil is scalding hot, and the plate is cleaned first with a palette knife, very broad and thin, then with a well-stuffed leathern boss; the plate is then placed on the plank, a piece of moistened tissue paper is brushed over with a very strong soap lie, then laid on the hot plate; both are run through the press: on the

Manufactures.

return the paper is rendered dry by the heat, and so imbibes the oil of the colour, yet leaves the colour distinctly adhering agreeably to the pattern. Very recently Messrs. Machin and Potts, of Burslem, have obtained a patent for printing the impressions for this purpose, by a machine and cylinders, something similar to cotton calicoes. The secrecy observed prevents a description being given here, but the results are entirely satisfactory to the patentees. The impression is received by a little girl, the *cutter*, who immediately cuts away all the white paper, separates the several parts, and places them so that they can be readily taken up by the *transferrer*, who performs the manipulation of fixing the pattern on the vessel. This requires much tact and judgment, equally to avoid breaking the vessels, as to ornament them with the design engraved. A roll of flannel, in length from 6 to 16 inches, is firmly tied together into a rubber; the ends are left soft, one to rest against the hollow of the right arm-pit, and the other to act upon the paper of the impression. The transferrer takes a biscuit vessel, places the several portions of the impression in their situations, at first gently, and afterwards most forcibly, rubs the whole upon the surface, until the paper is almost rubbed into the substance of the ware, whose absorbent property receives the oil, while the cobalt and alumine combine by their peculiar chemical tendency for each other. The vessel is afterwards placed on a board, and when a certain number is finished each is immersed in a tub of water, and a brush and a little soft soap are used to wash off the paper, and leave little beside the mineral colour.

When the ware has been treated in this manner, it is placed in a highly heated room, where it is made very hot, to evaporate the water imbibed by the biscuit ware, then for hardening on it is made red to volatilize the oily and destroy the carbonaceous particles. Both these processes are indispensable, as the omission of either would leave existing an obstacle to the proper adhesion of the watery medium of the *glaze*, when the ware is immersed to receive that necessary coating.

The workmen in France substitute for tissue paper a thin layer of glue, as will be now described under what English workmen denominate

Black Printing.

Black printing.

(667.) This manipulation is adopted to transfer to the glazed surface patterns from copper-plates, different in design and execution from those adopted in *blue* printing. The workman boils a certain weight of glue in a given quantity of water from four to six hours, so that when it is poured out on large and well-glazed flat dishes, in sheets of about a quarter of an inch thick, pieces of it will be completely flexible, yet have the consistence of dressed leather. When the glue is cold, the workman cuts the sheets into pieces of the size of each plate, the technical appellation *papers* being applied by some, and *bats* by others. The metallic calc used for the colour is rubbed in a saucer till completely dry and in the state of an impalpable powder, and a lock of dry carded cotton is used to apply it. Each plate is secured with rosin to a small prism of wood, for the convenience of holding in one hand, while with the other the oil is rubbed into the engraving, and the outer edge neatly cleaned. (For *Oil* see the recipe already given.) A glue paper is placed on a flannel fastened over a semicircular block of wood; on this the plate is pressed with a force sufficient to ab-

stract out of the lines of the plate the oil rubbed therein. The plate is laid aside, and the paper is applied by a gentle pressure to the surface of a vessel, then carefully taken off and applied to a second vessel, (where the work is of the usual kind;) the paper is then cleaned with a damp sponge and left to dry. The vessel is taken up, and, with the cotton, the colour is applied to the moistened surface; other vessels are similarly submitted to the papers until these require longer time to resume their adhesive power. The printer then cleans off all the superfluous colour with old silk rags, and with others wipes all the surface to which any particle of colour might possibly adhere.

Much tea ware, after being printed by either method, undergoes a further process, the upper edges being *topped*, and certain parts *lined* with gold or other colour. Any other ornaments deemed proper are added by the artists, and when dry, the articles are placed in those parts of the muffle where proper heat will be applied in the final process of baking the enamel.

Enamelling.

(668.) Whatever colours may be required by the design, Enamel landscapes, flowers, or figures, with which the porcelain is to be ornamented, the artist mixes a small quantity of each, according to its nature, on his well-glazed earthenware tile, with the smallest portion of oils of tar and turpentine, proper to cause the whole to flow readily from the pencil, in either clearly marked fine strokes or in spread layers, varied in hue by the changing quantity of colour. The oil evaporates quickly, and the vessel is ready for the muffle for the final baking; the carbon is dissipated by the heat, and the vitrification of the flux softens the part of the glaze on which it is traced, by which the metallic calcs become partially fused together. Excess of oil in the working prevents the close flow of the colour in baking, and the design is therefore meagre and imperfect in execution and brilliance.

Most metallic colours on porcelain exhibit all their beauty and brilliance when drawn out of the muffle, the greater number of articles requiring enamel-baking only *once*. As every layer of colour, however, can only have the flux vitrified and the metallic calcs fixed, some require to be *twice* in the muffle, and the finest specimens, which have groups of flowers and choice landscapes with figures, require several repetitions to give the different tints the desired beauty and brilliance.

The *grounds* are formed by a very even layer of linseed oil, red lead, and turpentine boiled two hours, and on which the impalpable powder of colour is evenly dusted by a lock of soft cotton wool.

Gilding.

(669.) The gold calc is ground very fine with a glass muller on a glass palette with oil of turpentine, the more readily to flow, as with a fine hair pencil the design is traced on the very clean surface of the glazed porcelain. Those vessels which have their edges or other parts decorated with a circular line are placed on a *whirler*, and the artist keeps his arm steady on a rest, as the hand holds the pencil to the proper part of the vessel. This implement consists of a pillar and claw resembling a tea table, but the pillar is bored deep, and the upper end has an iron hoop and a thumbscrew to receive and regulate the depth of an iron bar, on whose upper end, placed in a socket, revolves the circular head of wood two inches

Mechanical Processes.

Manufactures

thick and twelve diameter. The workman fixes the proper height of the head, places the claws so that his feet preserve the whole steady, and then, while with one hand he gives motion to the head, with the other he applies the gold (or colour) in very fine or broad lines as required.

The process of baking the gilded ware separates the oxygen of the metal, and leaves the gold in its metallic state, but in appearance of a dull brown colour like tarnished brass; therefore, to be recovered, and to secure the full effect of its beauty and usual brilliancy on those parts of the porcelain which are thus ornamented, the manipulation of burnishing with agate, bloodstone, or other polishing substances, is effected chiefly by young females with great care, because the baking may have been too soon concluded, and the gold may in consequence *chip off*, separate in thin flakes, or it may have been too intense, and prevent the proper lustre of the metal. In proceeding, the article is handled only by a cloth, and after slightly touching a part of the gold with a little white lead and water, the burnisher is applied, very quickly moved over each part, always in one and the same direction, to avoid *scratches* by crossing, and when the bright vivid lustre is raised, the vessel is wrapped in tissue paper.

Leaf-gilding, for the least valuable porcelain, is applying a warm size of half a pint of pure linseed oil, and half an ounce each of gums arabic and benjamin, and acetate of lead well boiled. This is laid very even on the edge of the ware, the vessel is heated a little, and the strips of leaf gold are applied, and adhere as the size cools.

Lustreing.

Lustreing.

(670.) Brushes of badger's hair of different breadths are used to apply to the glaze of the vessels the acidulous solution of metals. When a design is to appear free from lustre, a correct sketch is traced with lamp-black and water, and is well dried; and on some vessels are seen sketches with a strong solution of metallic oxide, over which, as well as all the other parts, is brushed, while the vessel is extremely hot, the lustre solution in a properly fluid state. When the lustre has been baked the metallic oxides have parted with their oxygen, but the metals have diminished brilliancy. The lamp-black is brushed off and the pattern is fully exhibited.

The *baking* of enamel, gilded, and lustre wares, is in an enamelling kiln, in form inside similar to a Chemist's muffle, but varying in size from six to twelve feet long, three to five feet wide, and three to five high. The vessels are carefully placed so as not to touch each other where any of the ornamental work is executed, and on props are placed flat earthen bats or iron gratings, so that the muffle has several tiers of vessels; the whole is secluded from any injurious vapours, and the process is from seven to ten hours. Trial beads are used in this process as in the others; but often the fireman ascertains the progressive vitrescence of the enamel colours, and determines when they are sufficiently baked upon the ware, by a small piece of dry wood cast in through a hole in the clammings, and its white flame during combustion exhibits the true tint of all the colours, not to be discerned on the red ware alone. See fig. 20.

The *gold lustre* is not difficult to make, yet care is requisite. Make a *balsam of sulphur* of best oil of turpentine 86, flowers of sulphur 14, in an earthen jug

gently heated not less than one hour; cool, decant the liquid, and to 60 parts add 40 more of oil. Over a slow fire again heat the liquid, and add to it gold solution 95, tin solution 5, by dropping in while carefully stirring it. Or,

On a plate or tile mix gold precipitate (above) with fat oil; heat gently, and when arrived at a liquid state add oil 25 parts, lower the heat and add turpentine 75 parts. (*Solid lustre*.)

The *silver lustre* is differently prepared. In aqua regia dissolve platinum to saturation, gently heat the acids, and gradually add to solution 25, spirits of tar 75; the nitro-muriatic acid evolves, leaving the platinum in the tar, which is evaporated for use.

Pipemaking.

(671.) This may be considered as a branch of the general Art of Pottery, although a distinct one, which is not so much dependent on locality as that described in the preceding pages. The clay used for the manufacture of these articles is found in different parts of England, but it is mostly obtained from the Island of Purbeck in Dorsetshire. Previously to being used, it must be purified from all extraneous matter, and reduced to the proper degree of tenacity, in lumps of about eighty or a hundred pounds' weight. From these, the pipemaker cuts off, from time to time, small pieces each of about the quantity to form one pipe; these are well kneaded, and afterwards rolled out on a board or table to nearly the size and form of the pipe, leaving a bulb at the end for the formation of the bowl. In this operation a skilful workman will roll the material into pieces of precisely the size and length required for the sort of pipes in hand. In this state the piece of rolled clay is placed in a mould, and all extra portions of it are cut away. It is then left to become a little hardened by drying; and when in a proper state, the stem is bored by introducing into it an iron or wire instrument furnished with a handle the full length of the stem. This operation calls for some address, and requires long practice. In performing it, the roll is taken between the fingers, which follow the end of the needle in its course through the whole length of the stem, a small enlargement being formed near the end, which is perceptible to the touch of the finger outside, and thus becomes a guide for its direction, which ought to be as nearly as possible in the axis of the pipe. This being done, the stem is next placed in a copper mould, divided into two parts, as shown in plate xlix. fig. 3. When intended to be used, the whole interior surface of both sections is slightly touched with a brush containing a little very limpid oil, that the stem may afterwards be delivered from it without difficulty. The roll of clay being placed in one section of the mould, the other is accurately fitted to it by means of marks previously made. The mould is then submitted to the action of a small iron press, by which the two halves are forced together, and all the exterior ornaments, &c., are impressed upon the clay.

It now remains to fashion the bowl. This is, in part, effected by the fore finger, and more perfectly afterwards by means of a stamp or form attached to the mould, and which, by the action of a lever, (acting somewhat like a patten-maker's knife,) is pressed within the hollow made by the finger for the purpose. The bore of the stem is then continued into the bowl, by pushing the instrument above-mentioned for boring the shank up to

Mechanical Processes.

Pipe-making.

First process.

Second process. Pl. xlix. Fig. 3.

Forming the bowl.

Manufac-
tures.

its handle; any superfluous clay is then cut away, and the pipe is smoothed by means of an iron or copper blade.

The pipes, as they are thus successively formed, are arranged upon a board; in order to their being further dried, and when they have acquired a certain consistency, any roughness which may appear is removed, and the bowl is rendered round and of shapely contour. They are then placed a second time in the mould, and all imperfections of shape are finally remedied. They are now left until sufficiently hardened to receive the last polish, which is given by rubbing them with flints bored with holes, some of which are of the same diameter as the stem, while others will admit the head of the pipe; and sometimes after this the ornaments are retouched with a tool. The needle is then withdrawn, and it only remains to harden the clay in the furnace or kiln.

The above description appears rather long, and the operation tedious. It is, however, by practice, performed with great expedition; at the same time it must be understood that some of the finishing processes are not bestowed upon any but the superior kind of articles. In common pipes many of the latter operations are omitted.

(674.) *Pipemaker's furnace*.—This is represented in plate xlix. fig. 4, 5; its peculiarity consists in admitting the heat to the pipes, while the flame, smoke, &c., which would soil the articles, are excluded. The crucible or seggar is of a cylindrical figure, terminated at the top by a hemisphere; it is placed over the fire-place *b*, inclosed within a lining of fire bricks *c*, and surrounded by an outer case of brickwork *d*. Between the lining *c* and the seggar is a space of about four inches all round, in which the flame from the fire-place circulates without interruption, except what arises from the numerous supports, which are necessary to sustain the seggar in its proper position; but as these are always placed edge-wise to the flame, and are very thin, they cause but little obstruction to its action.

These supports are twelve ribs between the seggars and the lining, which form the same number of flues, as shown by the dotted lines. The ribs are perforated with occasional apertures, to connect one flue with the adjacent one; but the principal bearing of the seggar is taken from five piers formed of bricks, projecting one over the other. One of these piers is placed at the back of the fire-place, and the other four at the sides, projecting at the top nearly into the centre of the fire-room, so as to support and strengthen the bottom of the seggar, which rests upon these piers; the spaces between which form the mouths or commencements of the flues, all these uniting in the dome *g* of the fire-brick linings, and this has a circular opening through it, leading into the chimney *h*.

The lining *c*, *d* of the seggar is open on one side, to form the door at which the pipes are taken in and out of the furnace; the opening is permanently closed as high as *k*, by an iron plate plastered with fire clay; above this the space is left open, and only closed when the furnace is burning, by temporary brickwork: when this is removed, the furnace can be filled or emptied through the opening. For this purpose the seggar has a similar opening in its side; and when the furnace is burning and the aperture is closed, the workman first spreads a layer of clay round the edge of the opening; he then sticks the stem of broken pipes across from one side to the other, and plasters the interstices with clay,

VOL. VII.

in a manner exactly similar to the lath and plaster used in building. The whole of the seggar is made in this manner; the bottom is composed of a great number of fragments of pipes radiating to the centre; these are coated with a layer of clay at the circumference, a number of the bowls of broken pipes are inserted into the clay, then other fragments are placed upright, to form the sides of the seggar. The ribs round the outside, which form the flues, are constructed in the same manner, as is also the dome *g* of the fire-brick lining; by this means the seggar is made very strong, but at the same time so thin, as to require but little clay to construct it, and is less liable to split by the heat, than a vessel formed of thicker materials. This method might be advantageously applied to other cases, where a very thin vessel or lining is required for a furnace.

The pipes which are to be baked are arranged within the seggar, the bowls resting against the circumference, and the other ends supported upon circular pieces of clay *h*, which are set up in the centre for that purpose. Six small ribs are made to project inward all round the crucible at the proper height, to support the different ranges of pipes without having so many resting upon each other, so as to endanger their being crushed by the weight. By this mode of arrangement the furnace is made to contain fifty gross, or 7,200 pipes.

These require from seven to nine hours to be burned: the heat is at first brought on gently, and afterwards increased to the full intensity required for baking this species of pottery. The fire is regulated by a simple kind of damper applied over the aperture in the dome *g* of the fire-brick lining. This is a mixture of horse-dung, sand, and pipe-clay well worked together, and spread in thin layers upon coarse brown paper. A sheet of this being laid over the pole in the dome, so as to cover more or less of it, will give the means of increasing or diminishing the draught, and, consequently, the heat of the furnace.

Glass Works.

(675.) Glass, if not an article of indispensable utility to mankind, is one which contributes largely to the comforts and elegancies of civilized life, and to the prosecution of scientific research. What substitute could we find for the glass which forms our windows, which while it admits almost without diminution the light and warmth of the sun, and allows us to see every thing within and without our houses with distinctness and facility, screens us from the effects of wind, rain, and tempest? And what can be conceived so beautifully ornamental as the rich services of glass we sometimes see, the splendid mirrors, chandeliers, and other decorative articles? In Science, Astronomy is altogether indebted to glass for its present accuracy and perfection, as is also Navigation, and the wonders displayed by the microscope would probably have ever remained hidden from human sight but for the aid of this extraordinary substance. Its manufacture, likewise, considered merely as a Mechanical Art, is extremely interesting, and will, therefore, call for more than usual detail; and its history, although it extends to very high antiquity, and is in its early part somewhat obscure, must also be attempted. For the latter we avail ourselves of a very neat and concise sketch published by Mr. Pellatt, of the firm of Pellatt and Green, whose works are scientifically conducted on a scale of considerable magnitude.

3 P

Mechanical
Processes.

Pipe-
maker's
kiln or fur-
nace.
Pl. xlix.
fig. 4, 5.

Glass
works.

Manufac-
tures.

History of
glass.

Of the Art
of glass-
making
known to
the Eryp-
tians.

Glass-
houses of
Alexandria
celebrated.

(676.) *History of Glass.*—The period when the Art of making glass was first discovered is certainly not known, but as it is scarcely possible to excite a fire of sufficient heat for metallurgic operations, without vitrifying part of the bricks or stones of the furnace, (a circumstance which would very naturally suggest the idea of glass-making,) it is probable that this Art is as old as that of working metals, which we have seen was anterior to any existing authentic records.

Glasshouses were at a very early period established at Tyre. Pliny states, that some merchants being driven by a storm at sea to the mouth of the river Belus, were obliged, during the time they were detained there, to dress their victuals by kindling a fire on the sand, where the herb kali grew in great abundance, and that the salts of this plant, on its being reduced to ashes, incorporated with the sand or with stones fit for vitrification, and thus produced glass. However this may have been, the sand which lay for about half a mile round the mouth of the river was peculiarly well adapted to the making of glass, while the extensive range of the Tyrian and Carthaginian commerce afforded an ample vent for the productions of the furnace.

The Art of glass-making was certainly known to the Egyptians, although there exist but few specimens of antiquity to prove the fact. Most writers have erroneously referred to the beads which ornament some of the mummies as satisfactory evidence on this head; but these are not composed of glass, but of burned clay or earthenware glazed, being of a substance precisely similar to the numerous small images of mummies, beetles, and other figures. There can, however, be but little doubt that the Egyptians were well acquainted with the materials for making glass, as well as with the chemical properties of the metallic oxides for covering it; since among the Tombs at Thebes have lately been discovered small solid pieces of glass of a turquois colour which exactly resemble, and perhaps were used for the glazing of the beads and figures of earthenware.

Fragments of white, yellow, and green glass, have likewise been found, but these may possibly have been made by the Greeks or Romans, who successively conquered Egypt, or they may have been procured from neighbouring or distant nations. Some of these fragments are flat, and of a circular form, resembling a coin nearly entire, and of an amber colour, having a well executed figure impressed upon them in bas-relief; others are of a green hue, with Arabic characters. The former are of the size of a sixpence, the latter as large as a half-crown piece.

It appears that the glass-houses of Alexandria were celebrated among the Ancients for the skill and ingenuity of their workmen, and from these the Romans, who did not acquire a knowledge of the Art till a later period, procured all their glass-ware. Strabo relates, that a glass-maker of Alexandria informed him, that an earth was found in Egypt without which the valuable coloured glass could not be made; and it is stated by Pliny, that in the reign of Tiberius, a Roman artist had his house demolished for making glass malleable; and that, in consequence of this discovery, glass came into such general use as to supersede cups of gold and silver, and the glass-makers became so important, that a street was assigned them in the first region of the City.

The Chinese also are known to have possessed considerable skill in this Art; M. Abel Rimusat states, that

the imitation of the precious stone Yeschm was so excellent, that it was impossible to distinguish the artificial from the real. This description of glass-ware was manufactured by the Chinese into vases of various forms, which were procured from them by the Arabians. Some were of a clear transparent white, extremely brilliant, and as pure as the precious stone; and others, of a beautiful blue, they imitated equally pure. In Egypt and Syria no difference was known between the real and the artificial Yeschm: the latter being of the same form, thickness, and specific gravity as the former. It is indeed asserted that in Cairo, and other parts, the artificial vases were as highly valued as those of the real Yeschm, and that enormous prices were given for them. The Chinese have also equally well imitated the Justone, which was too costly for persons of a moderate fortune. It is a coloured glass of rich appearance and greenish tint, and of such hardness and weight that it very frequently surpasses the real Ju. Small vases, figures, and almost every description of ornaments that are sculptured in the real stone, were made in this description of glass. A specimen of this imitation may be seen at the British Museum; it is of a bluish-white, resembling enamel, of an octangular figure, and about the size of a snuff-box; it is extremely hard, and, in proportion to its size, of an astonishing weight.

A most singular Art of forming pictures with coloured glass seems to have been practised by the Ancients, which consisted in laying together fibres of glass of various colours, fitted to each other with the utmost exactness, so that a section across the fibres represented the object to be painted, and then cementing them into a homogeneous mass. In some specimens of this Art which were discovered about the middle of the last century, the painting has on both sides a granular appearance, and seems to have been formed in the manner of mosaic work, but the pieces are so accurately united, that not even with the aid of a powerful magnifying glass can the junctures be discovered. One plate, described by Winkelmann, exhibits a duck of various colours, the outlines of which are sharp and well defined, the colours pure and vivid, and a brilliant effect has been obtained by the artist having employed in some parts an opaque, and in others a transparent glass. The picture appears to be continued throughout the whole thickness of the specimen, as the reverse corresponds in the minutest points to the face, so that, were it to be cut transversely, the same picture of the duck would be found exhibited in every section. It is conjectured that this curious process was the first attempt of the Ancients to preserve colours by fusing them into the internal part of glass, which was, however, but partially done, as the surfaces have not been preserved from the action of the atmosphere.

(677.) The subterranean ruins of Herculaneum afforded many specimens of the glass-manufacture of the Ancients: a great variety of phials and bottles were found, and these were chiefly of an elongate shape, composed of glass of unequal thickness, of a green colour, and much heavier than common glass; of these the four large cinerary urns in the British Museum are very fine specimens. They are of an elegant round figure with covers, and two double handles, the formation of which must convince persons capable of appreciating the difficulties which even the modern glass-maker would have in executing similar handles, that the Ancients were well acquainted with the Art of making round glass vessels, although their know-

Mechanical
Processes.

Knowledge
of the
Chinese in
making
glass.

Specimens
of glass
found at
Hercula-
neum.

Manufactures.

ledge appears to have been extremely limited, as respects the manufacture of square vessels, and more particularly of oval, octagonal, or pentagonal forms. Among a great number of lachrymatories and various other vessels in the British Museum, there is a small square bottle with a handle, the rudeness of which sufficiently bears out this opinion.

Portland vase.

(678.) The most celebrated antique vase is that which was during more than two centuries the principal ornament of the Barberini Palace, and which is now known by the name of the Portland vase. It was found about the middle of the XVIth Century inclosed in a marble sarcophagus within a sepulchral chamber under Monte del Grano, two miles and a half from Rome, supposed to be the Tomb of Alexander Severus, who died in the year 235. It is ornamented with white opaque figures in bas-relief upon a dark-blue transparent ground, the subject of which has not hitherto received a satisfactory elucidation; but the design, and more particularly the execution, are truly admirable. The whole of the blue ground, or at least the part below the handles, must have been originally covered with white enamel, out of which the figures have been sculptured in the style of a cameo, with most astonishing skill and labour. This beautiful vase is sufficient to prove that the manufacture of glass was carried to a state of high perfection by the Ancients.

Venice during a long period excelled all Europe in the fineness of its glass. Judging from the curious specimens to be seen in this Country, the Venetian glass-blowers must have been artists of considerable skill; and the Bohemians were also formerly very celebrated for their extensive glass-works. They invented a curious method of ornamenting glass-ware, which has since become well known, and was at one time in much repute in this Country; this consisted in inclosing in the stems of wine-glasses and goblets white and coloured opaque enamel tubes, which they twisted in white transparent glass.

First knowledge of glass-making in Britain.

(679.) Glass-making in Britain is supposed to be of very ancient date; and, if the opinion of Pennant be well founded, of a date prior to the Roman conquest. The Art of manufacturing glass, as beads and amulets, was certainly long known to the Druids, as rings termed the *glain neidyr* or Druid glass rings are very frequently found near Aberfraw Palace. The glass amulets are about half as wide as our finger rings, but much thicker; they are usually of a green colour, but some are blue, and others curiously variegated with waves of blue, red, and white. They are said to have been used by the Druids as a charm to impose upon the vulgar.

Window glass.

It is very uncertain when glass was first employed for the transmission of light and other optical purposes, or how long any of the nations of Europe have enjoyed the benefit of glass windows. One of our oldest English Historians, Bede, tells us that in the year 674 the Abbot Benedict sent for artists from abroad to glaze the Church and Monastery of Weremouth in the County of Durham.

Notwithstanding the interest which so important an application of glass was likely to occasion, it is probable that glazed windows were not common in these kingdoms till several centuries after the period above-mentioned. Dr. Henry says, that although the Art of glass-making was introduced in the VIIth Century, yet it was afterwards so much neglected, that no private house had glass windows till after the conclusion of the Xth Century. Before this period, the windows of houses, and

even of Cathedral churches, admitted the light through fine linen cloths or lattices of wood.

Mechanical Processes.

The first glass-houses of any importance established in England, were those at Crutched Friars, and in the Strand, London, about the middle of the XVIth Century. The Art was afterwards encouraged by King James I. and Charles I., both of whom prohibited the importation of all foreign glass, excepting that of the most inferior kinds. The former of these Monarchs, as an expedient to raise money without the aid of Parliament, granted to Sir Robert Mansel an exclusive patent for making glass, which was afforded him in consideration of his having established the use of pit-coal for wood in its manufacture. He was also allowed, on the same ground, the exclusive privilege of importing drinking vessels, and every other article of glass from Italy, which could be made of a finer quality than had at that time been produced in England.

The second Duke of Buckingham has the merit of improving the manufacture of British glass by bringing over several workmen from Venice: he established a considerable manufactory for making plate glass at Lambeth about the year 1670.

During this interval, glass-making had made considerable progress in France. So early as the commencement of the XIVth Century, the French Government had encouraged this manufacture, by ordering that gentlemen or the sons of nobility might exercise the trade without derogating from their rank; but no great advance was made until the Minister Colbert, by a fortunate event, was enabled to lay the foundation of a manufactory upon the most improved principles.

Certain French artists, established at Venice, found means to obtain at Murano an exact knowledge of the processes employed in the fabrication of plate glass, and they returned to France with the hope of enriching their land with that splendid branch of Art and Commerce. The Minister received them graciously, and having empowered them to select such a situation as they might deem best suited to their undertaking, they established themselves, in the year 1665, at Tourlaville, near Cherbourg. This Company afterwards obtained a patent for making plate glass, and an advance of 12,000 livres for four years was granted them for this purpose by the French Government.

In the year 1688, Abram Theuart, an ingenious manufacturer, made a proposal to the Court for casting glass mirrors, and engaged that they should be of a larger size than any that had been before made. This individual likewise obtained a patent, to continue for thirty years; and the first plates which he cast were made at Paris, and were of the extraordinary dimensions of 84 inches by 50 inches, a size which surprised all the artists of that day. Notwithstanding this success, not more than three years elapsed before the proprietors found it expedient to move their establishment to St. Gobin, in the department of the Aisne, and there they laid the foundation of a manufactory which soon became, and continues to remain, more extensive than any in Europe.

To return again to England, we find the Art advancing with the same, and even a greater degree of rapidity. In the year 1773, a respectable Body of gentlemen obtained a Royal Charter of incorporation, the privileges of which were confirmed to them by Act of Parliament, under the title of "The Governor and Company of British Cast Plate Glass Manufacturers."

Manufac-
tures.

They subscribed a capital or joint stock of eighty shares, of £500 each, and constructed works of considerable extent at Ravenhead, near Prescot, in Lancashire, which still rank among the most important glass-works in this Country.

The Art of glass-making, having been thus patronized by the Nobility and Gentry of the Country, soon made rapid progress, and the attention of scientific men being directed to this subject, great improvements and facilities were introduced in the manufacture; and it may

now be said that we equal, if not excel, those Countries which were formerly our instructors, both in the beauty of the material, and in the variety and elegance of the various utensils into which it is manufactured. The present extent of this Art will be seen from the following Table, giving the quantities of different kinds of glass which have been charged with duty, and the net produce thereof in each year from 1820 to 1831.

Mechanical
Processes.

Years.	Flint Glass.	Fluxed Materials for Flint Glass.	Plate Glass.	Crown Glass.	Broad Glass.	Green Glass.	Total Produce of Duties.
	Cwts.	lbs.	Cwts.	Cwts.	Cwts.	Cwts.	£.
1820	50,878	....	8,855	97,309	7,253	321,470	405,940
1821	52,016	....	9,650	97,273	8,704	276,323	439,477
1822	56,583	....	10,198	103,193	7,921	286,927	502,813
1823	67,299	....	12,107	119,493	9,172	343,293	549,358
1824	63,442	....	13,922	141,463	9,300	376,287	635,496
1825	33,367	8,806,234	15,642	160,709	8,386	393,567	660,532
1826	...	16,040,182	19,958	135,606	8,118	421,902	623,786
1827	...	16,819,656	14,807	138,744	7,611	818,225	619,297
1828	...	18,501,504	16,641	137,950	6,784	421,003	598,640
1829	...	19,961,504	13,526	105,097	6,181	365,802	653,206
1830	...	16,232,384	14,296	98,287	5,635	338,862	550,499
1831	...	16,627,408	14,109	103,803	5,609	288,760	531,494

On the Ingredients employed in the Composition of Glass.

Materials
employed.

(680.) Glass is produced by fusing silica with a due proportion of alkali, which acts as a flux to the silica, and renders the whole transparent. Besides these two ingredients, which are absolutely essential to the composition of glass, the following accessory substances are employed, which, by their chemical action, give peculiar properties to the different kinds of glass; viz. borax, carbonate of lime, oxide of lead, oxide of manganese, white oxide of arsenic, and nitre.

The silicious material most commonly used in this Country for the manufacturing of glass is sea sand, which is well known to consist chiefly of quartz; it has the advantage of being naturally divided into grains, sufficiently small to be used without any other preparation than that of washing. The finest sand is said to come from near Lynn, on the coast of Norfolk, and from the Western extremity of the Isle of Wight. Another equally pure kind of silex is the common black flint, which is prepared by heating it red hot and plunging it into cold water, which splits it in every direction, and renders it so brittle that it can be ground in mills without much difficulty. This kind of silex is, however, more commonly used in pottery than in glass-making.

Alkali.

The alkali used in this manufacture is either soda or potash, each being apparently equally well fitted for the purpose. It is preferred in the state of the carbonate, although the carbonic acid is drawn off by the heat of the process; the glass being a compound of silex with pure alkali, and not with the carbonate. For fine flint glass the best pearl-ashes, purified by solution and evaporation to dryness, are employed, but the inferior glasses are made with the coarser alkalies, with barilla, where this alkali is cheap, with common wood-ashes, and

very largely with kelp. Although these last-mentioned alkalies contain many impurities it does not prevent their dissolving the silex into a very good and perfect glass, for the impurities partly consist of neutral salts and partly of lime and other earths, all of which assist in the vitrification. Glass made from these alkalies has always more or less of a green tinge, owing to a portion of iron contained in them, as may be observed in the common bottle glass.

Borax is very important in the manufacture of the finer sorts of glass, from its powerful action as a flux; but it is not used in the common kinds, on account of its high price. Borax is a compound of soda and boracic acid; it is found native in several parts of the world, but is exported into this Country from the East Indies, under the name *tinzel*, which is in a very impure state, and has to be prepared for use by calcination and solution.

Borax.

Lime is employed in the form of chalk as a flux; it is also beneficial in facilitating the operations of the workmen in fashioning glass, and it has the property of diminishing its liability to crack on exposure to sudden and great variations of temperature. Lime is used in small proportions in the glass pots, for the escape of the carbonic acid from the chalk during the fusion causes the materials to swell to an inconvenient degree, and also if the lime is in excess it acts very powerfully on the sides of the pots.

Lime.

In making plate glass quicklime is very commonly employed; but it is necessary that it should be of the very best quality. The limestone brought from Gibraltar as ballast is found to produce much better lime for the purpose than the chalk in the neighbourhood of London; but it is said that the best lime for the glass business is that of St. Vincent's rock, near Bristol.

Two kinds of oxide of lead are used in glass-making viz. litharge and minium. Litharge will melt by lead.

Oxides of

Manufac-
tures.

itself into a very dense, clear, transparent glass, remarkably soft and unctuous to the touch, fusible at a very low red heat, and when melted acting so powerfully on all earthen vessels as to run through the common porous crucibles in a very short time, almost like liquor through a sieve, vitrifying and corroding the bottom of the crucible in its passage. Litharge is therefore a most powerful flux to all earthy mixtures, and it imparts to the glass the valuable qualities of greater density and greater power of refracting rays of light, and of bearing sudden changes from heat to cold without being so liable to crack; it gives also greater tenacity when red hot, and therefore is easier to work.

(681.) Most of the finer glasses contain a considerable quantity of this oxide, particularly the London flint glass, which is used for the purposes of the table, for lustres and other ornamental works, for artificial gems, for optical and a variety of other purposes. Glass containing much lead has, however, the defect of being extremely soft, so as to be readily scratched and injured by any hard body which rubs against it. It is also extremely fusible, so that thin tubes of it will bend with ease in the flame of a candle, and will sink down to a shapeless mass at a very moderate heat.

Glass for
optical pur-
poses.

For optical purposes another great inconvenience attending the use of lead is, that it does not become sufficiently intimately united with the other components for the whole mass to assume a uniform density. It will always happen that the glass at the bottom of the pot contains a larger proportion of litharge than that above. This inequality subsists throughout, so that every stratum of the melted mass is of intermediate density between the stratum above and that below, which is irregular refraction in the glass when wrought; and as for optical purposes the perfectly uniform density of the material is of the greatest importance, this defect is very detrimental to the use of flint glass. The difficulty of obtaining a piece of flint glass sufficiently large for the object of a large telescope, and at the same time perfectly pure, is so great, that as large a sum as £1000 has been given for one piece of glass. Various attempts have in consequence been made to obtain a glass which should have sufficient refraction, and yet not be liable to these defects, and the Royal Society undertook an extensive set of experiments, which were placed under the direction of Dr. Faraday, a Report of which will be found in the *Philosophical Transactions* for 1830.

Black oxide
of manga-
nese.

(682.) The black oxide of manganese has been used for many years in the manufacturing of glass before its precise nature was understood. Its ancient name was glass soap, which denotes its use; namely, that of clearing the glass from any accidental foulness of colour which it might contract from the impurity of the alkali or other materials employed, and particularly from the green tinge, which is owing to the presence of iron.

The circumstances attending the employment of this substance in glass-making are rather of a curious nature. When added in a moderate proportion to any simple glass it imparts a purple hue, and should its quantity be very great the colour is deepened until it becomes nearly black. If, while the mass thus coloured is still in fusion, white arsenic, charcoal, or other carbonaceous matter be added, an effervescence is sure to follow, and the tint becomes gradually more faint until it altogether disappears, and the glass is rendered clear and transparent. Provided the green hue which it is desirable to counteract be considerable, the application

of a small quantity of manganese is not followed by any sensible tinge of purple: but the moment the proportion is more than sufficient for that purpose, the colour immediately appears and must be corrected, which is performed in a very simple manner in the glass-house, by twisting into the pot of melted glass a piece of wood, which, becoming charred by the heat, causes the purple again to vanish; while a slight effervescence, and an escape of numerous bubbles of air, are plainly perceptible.

Mechanical
Processes.

The oxide of manganese is of use from its property of powerfully assisting in the fusion of earthy bodies. It also gives considerable density to glass, but the same disadvantage accompanies its use as already has been noticed with regard to litharge; viz. having from its greater specific gravity a tendency to settle to the bottom of the pot; in addition to which manganese acts injuriously upon the pots, by corroding them at the bottom.

The white oxide of arsenic is another flux used pretty largely in glass-making. This substance being volatile as it approaches the metallic state, it is of advantage to employ nitre to oxygenate it more highly, and make it more fixed. Arsenic is a very powerful flux, and very cheap, but it must be used only in moderation, from the circumstance of its taking a longer time to mix intimately with the glass, and to become perfectly clear, than any other of the additions commonly employed. Glasses in which arsenic is not thoroughly fused have a milky hue, which increases by age when the arsenic is in excess; they have a tendency to become soft, are decomposed, and are therefore unsafe for drinking vessels. The arsenic is constantly volatilizing from the arsenical glass when preparing, until it is intimately united with it, after which it cannot be separated by heat or any common means.

White
oxide of
arsenic.

As arsenic is entirely volatilized when in contact with any carbonaceous matter, it has been made useful in dispersing any substance which may remain in the glass, owing to a defect in the calcination of the alkali or any other cause. When this happens, small lumps of white arsenic are sometimes thrust down to the bottom of the glass pots, and stirred in with the contents; and the arsenic, meeting with the unburned carbon diffused through the glass, carries it off by volatilization, and the glass is left free from the adhering colour, and the greater part of the arsenic which was added. The motion excited throughout the melting glass, by the volatilization of the arsenic, is also thought useful in hastening the complete vitrification of the ingredients.

Nitre is used in destroying any carbonaceous matter in the ingredients with which it should be mixed before fusion. It is also useful in destroying a red purple tinge which is given by manganese.

On the Proportion of Ingredients in different Kinds of Glass.

(683.) There are five distinct kinds of glass at present manufactured.

Proportion
of ingre-
dients in
different
kinds of
glass.

1. Flint or crystal glass.
2. Plate glass or glass of pure soda.
3. Crown glass, the best window glass.
4. Broad glass, a coarse window glass.
5. Bottle or coarse green glass.

Flint glass, so named because the silicious ingredient originally employed was ground flints, is the most bril-

Manufactures.

lial and beautiful vitreous compound with which we are acquainted; and although the quantity manufactured may fall short of some of the other kinds of glass, yet its uses are so much extended and so important as to give it the first rank in this description of manufacture.

The composition commonly employed for it in this Country is as follows:

Purified Lynn sand.....	100 parts
Litharge or red lead.....	60
Purified pearl-ash.....	30

To correct the green colour, a little black oxide of manganese is added, and sometimes nitre and white oxide of arsenic.

Loysel recommends the following composition for crystal, where coal is employed as fuel:

White sand.....	100 parts
Minium.....	80 to 85
Pearl-ash.....	35 to 40
Nitre.....	2 to 3
Oxide of manganese.....	6

Where wood is used for the reduction of the ingredients, and where the crucibles may be left uncovered during the process, a different mixture is preferred. In this, a much smaller proportion of metallic oxide is added, the reason of which M. Loysel states to be that the air, having constant and unimpeded access to the surface of the glass, supplies any deficiency of oxygen, while the process through the direct application of heat is more quickly performed, and the glass is harder and more durable.

Dr. Faraday's glass.

(684.) Dr. Faraday, in his experiments to obtain a glass which should be perfectly homogenous and fit for optical purposes, made use of the following composition:

Nitrate of lead.....	154.14
Silicate of lead.....	24.00
Crystallized boracic acid.....	42.00

These proportions, when heated and submitted to a mutual action on each other, produced 152 parts of glass, containing

Protoxide of lead.....	112
Silica.....	16
Dry boracic acid.....	24
	152

The nitrate of lead was procured from litharge, by first washing, in order to separate the carbonaceous and ferruginous particles, and then dissolving it in dilute nitric acid, so as to form a hot saturated solution.

The silica was the common flint glass-maker's sand, from the coast of Norfolk, and the silicate of lead was prepared by mixing two by weight of this sand with one of litharge. The mixture was put into a large Hessian or Cornish crucible, which, being covered over, was placed in a furnace, and raised to a bright red heat for eighteen or twenty-four hours. On taking out the crucible the charge was found somewhat diminished in bulk, and of a porous structure and appearance, like loaf sugar. Before being used, the outside portions were removed and the pure parts carefully pulverised in a clean Wedgwood mortar, and afterwards washed over in water so as to obtain the whole in a fine state of division.

The advantage of silica in this combined state Dr. Faraday states to depend upon the composition of the substance, its comparatively easy pulverisation, and ready fusion with other metals.

This ingenious Philosopher formed a great variety of glasses with different proportions of ingredients, which

varied considerably from each other, although by no means to the extent of the difference between them and common flint glass. The specific gravity is very high in that made with borate of lead, consisting of single proportions; that is, nearly 24 by weight of boracic acid and 112 of oxide of lead: it is often as high as 6.39 or 6.4, being double that of some specimens of flint glass. In that made with the silicated borate of lead, which, in addition to the former qualities, contains 16 parts, or a proportion of silica, the specific gravity is about 5.44, that of ordinary flint glass being 3.290 and Guinaud's, 3.616.

The refractive and dispersive power was found to increase, as might have been expected, with the specific gravity. The power of two kinds, namely, borate of lead, and silicated borate of lead, have been ascertained by Sir John Herschel, and are as follows:

	Bor. Lead.	Sil. Bor. Lead.
Angle of glass prism.....	29° 6'	30° 26'
Refractive index for extreme red rays.....	$\mu = 2.0430$	1.8521
Ditto maximum yellow..	$= 2.0652$	1.8735
Ditto extreme violet.....	$= 2.1223$	1.9135
Dispersive index $= \frac{\delta \mu}{\mu - 1}$...	0.0740	0.0703

These intense powers upon light are not accompanied by any circumstance rendering the glass optically unfit for the compensation of the dispersive powers of crown or plate glass. Three object glasses were constructed for the express purpose of ascertaining this point, and all of them tend to demonstrate that the compensation or correction may be effected with equal if not greater facility than with flint glass.

In point of hardness these glasses differed as much from each other as in any other quality, and, indeed, more so. The borate of lead is very soft, the bi-borate of lead is harder, and the tri-borate equal to flint glass in hardness. The silicated borate of lead is softer than flint glass, but the glass consisting of one proportion of oxide of lead, one of silver, and one and a half of boracic acid, is as hard as ordinary flint glass; at the same time it has a degree of fusibility, colour, and other properties which renders it a very promising variety. The hardness increases with the diminution of the oxide of lead, but the fusibility diminishes in the same proportion; and this is a property which is essential to preserve to a certain degree for the removal of striæ and bubbles.

Many other useful results were deduced by Dr. Faraday from his experiments, which the limited extent of this Essay will not permit us to notice. We, therefore, again refer the reader to the *Philosophical Transactions* for 1830, where a detailed account of the experiments is given.

Plate Glass.

(685.) In the formation of good plate glass, one of the most important considerations is the preparation of the soda, which is the alkali preferred. This is done by decomposing the muriate of soda (common salt) by means of subcarbonate of potash, both salts being in a state of solution assisted by heat. After this, a portion of muriate of potash is separated from the solution by priority of crystallization, when the remaining alkaline solution is boiled down to dryness and reserved for use.

After the alkaline salt has been thus prepared, it is in

Mechanical Processes.

Manufactures.

some measure necessary to analyze it, with a view to ascertain how much real alkali it contains, and, hence, how much sand it will require. When this is known, the calculation is made without any difficulty, for it is found that one pound of pure soda is sufficient for four pounds of sand, to produce a hard compact glass, which cannot be injured by the action of water, or even by the common mineral acids. Thus, if the prepared alkali should contain 40 per cent. of real soda, which is about the usual quantity, the remainder being muriate of potash, carbonic acid, and water, the operator should take 160 pounds of sand to every 100 pounds of such salt. Upon these data Mr. Parkes gives the following proportions of the materials to produce a glass suitable for the best plates.

Lynn sand previously well washed and dried	720 pounds
Alkaline salt prepared as above.	450
Quicklime slacked and sifted	80
Nitre	25
Cullet or broken plate glass.	425
	1700

If the process be well conducted these quantities of different materials will produce one pot of metal, containing 1200 pounds of good plate glass.

Dr. Ure gives for the best proportion of the materials,

Pure sand.	43
Dry subcarbonate of soda. ...	26.25
Pure quicklime	4
Nitre.	1.5
Broken plate glass.	25.0
	100

From which about 20 parts of good plate glass may be run off.

The lime is of considerable use here, adding much to the fusibility of the materials, supplying in this respect the use of litharge in the flint glass; too much lime, however, impairs the colour and solidity of the glass. About one-fifteenth of the whole is as much as can be used with propriety; and some use as little as one-twenty-fourth.

The substances added to destroy the colour are cobalt blue, and manganese. The manganese is in sufficient quantity to impart a slight red tinge, which, when intermixed with the blue of the cobalt and natural yellow of the other materials in proper proportions, is found to neutralize them so that scarcely any definable tint remains.

Crown Glass.

Crown glass.

(686.) The alkali employed for this description of glass is generally kelp, but being an alkali which varies so much in its quality, it is difficult to give any defined proportions for its use. The following are the most common:

Irish kelp dried and ground. .	450 pounds
Lynn sand dried.	325
Slacked and sifted lime	25
	800

In addition to these substances, a quantity of arsenic is very commonly added to facilitate the fusion; and zaffre or the oxide of cobalt, with ground flint, is also used to correct the dingy yellow, which the inferior kind of crown glass naturally acquires, and by thus adding the blue, natural to glass coloured with this oxide, the whole

is converted into a soft green light. The green hue thus given is very slight, and not disagreeable to the eye, and is hardly perceptible unless the light pass through a great thickness of glass, as happens when a piece is held edgewise. The quantity of zaffre necessary for this effect is extremely small, one ounce being sufficient for 1000 pounds, and when the alkali and sand are good none at all is required.

Mechanical Processes.

The Orkney kelp is sometimes preferred for window glass, because it makes it of a better colour than the Western Isle or the Scotch kelp. Mr. Bowles, the celebrated maker of crown glass, at Cock-hill, Radcliffe-highway, London, is said always to have used Spanish barilla instead of kelp, and his glass was generally preferred to that of others.

Broad Glass.

(687.) Broad glass, although employed for the purpose of window glass, is quite a distinct manufacture to that of the crown glass, both with respect to the materials employed and the process of fabrication.

The ingredients are soap-boiler's waste, kelp and sand, in about the proportion of six bushels of the first to three bushels of kelp, and four of sand; but from the great variability of the qualities of these materials there is no absolute rule for the proportions. Loysel has stated, as the result of his own experience, that if coarse sand be used, two pounds of pure alkali must be put to every four pounds of sand, or it will not melt; but if the sand were very fine, one pound of pure soda would be sufficient.

Green Bottle Glass.

(688.) This is the coarsest description, and executed in greater quantities than any other kinds of glass, so much so, that one half of the entire manufacture of this material in Great Britain is of this kind.

It is commonly made of soap-boiler's waste and sand, in various proportions, according to the quality of the materials. Sometimes a portion of kelp is also added, but this is not used in all manufactories. In consequence of the rate of duty being only one-eighth of that levied upon flint, the manufactories are restricted to the use of the commonest kind of sea or river sand, lest the revenue should suffer by the superior quality of the less-burdened ware. This use of so coarse a sand occasions the necessity of the employment of a large portion of alkaline matter, and in this respect increases the charges to the glass-blower. The impurity of the alkali, and the abundance of fluxing materials of an earthy nature, joined to the very high degree of heat at which they are fused, occasion the glass to contain a very small proportion of saline matter, for which reason it is better qualified than flint glass for the recipient of fluids which have any corrosive action; chemical retorts, sublimary vessels, and carboys for containing aquafortis, should for this reason be always made with the common glass, which has this further advantage over the flint that it will bear a much stronger heat without being softened or undergoing any alteration of shape.

Bottle glass is very hard and well vitrified, and is of less specific gravity than other descriptions. The composition employed in France to produce this material, as given by Loysel, is

Common white or yellow sand. . .	100 parts
Coarse kelp.	30

Manufactures.

Lixivated earth of ashes	160
Brush wood or other ashes	30
Brick clay	80

To which is added a quantity of broken glass, generally to the amount of 100 parts.

At Newcastle-upon-Tyne, where the manufacture of bottle glass is much encouraged, by the excessive cheapness of small coal or slacks, the manufacturers employ a mixture of lime and sea sand. The sand is frequently melted with sea water, which, on evaporating, deposits its salt, of which the soda contained is the only alkali employed. When combined with silica and exposed to a high degree of heat, lime appears to be endowed with the property of decomposing common salt; its presence is therefore essential to the success of this operation.

On the Fusion of Glass.

Fusion of glass.

(689.) The operations of the glass-house admit of being divided into two distinct classes; viz. those connected with the fusion or formation of the material itself, and those connected with its manufacture into the various articles for which it is employed. Under the present head we speak simply of those processes necessary to bring the glass into a proper state to be operated upon by the glass-manufacturer.

Fritting.

The first process in glass-making is that of preparing the materials for the glass pots, which is termed fritting, and consists in calcining them to a point of semivitrification, in which they strongly adhere, and begin to become pasty, but are still opaque, and not yet homogeneous. This process is sometimes performed in small furnaces adjoining the glass furnace, and heated by the same fuel after the chief force has been spent upon the glass pots, although generally small furnaces or ovens are constructed for this express purpose.

The uses of this operation are to drive off the moisture from the materials, which might endanger the destruction of the glass pots, and to expel the carbonic acid from the alkalis and chalk, by which the swelling of the materials is prevented.

This calcination has also the further advantage of causing a chemical union to commence between the alkali, silex, and metallic oxides. For if the raw materials were immediately exposed to the intense heat of the glass pots, the alkali would flow like water, and the grosser particles of the sand, and the heavier oxides, would settle to the bottom, leaving the alkali above nearly disengaged, and thereby liable to act on the crucibles; besides which a large portion would be rapidly volatilized to mere waste. The glass materials would thus have an excess of sand from the loss of the alkali, and a portion would remain at the bottom unvitified.

These operations do not apply to the preparations of materials for flint glass, the fusibility of which is much greater than that of any other description, owing to the presence of so large a portion of lead. For this reason, manufacturers of this kind of glass apply the process of calcination to the sand alone, with a view of separating from it all carbonaceous impurities, previously to its admixture with the remaining materials.

When the process of calcination or fritting has continued for a sufficient length of time, which varies from six to twenty, or even to a greater number of hours, depending upon the materials employed, the substance, which is in a softened state, is either made into the form of square cakes, known to the workman by the name of

frit, to be preserved for future use, or thrown at once into the crucibles in the furnace, where the fire has been previously raised to its greatest intensity. As the fritted materials are much more bulky than when fused, the pots receive their full charge by two or three successive portions, the last added being always thoroughly melted down before a fresh charge is thrown in. When the pots are full, the side opening in the furnace, by which the materials are admitted, is closed up (except a small opening for examining the work) until the complete fusion and refining of the materials has taken place.

(690.) As soon as the frit begins to feel the action of the fire in the glass pots, it sinks down into a soft pasty mass, and gradually increases in tenacity until a perfect fusion is effected. It is still, however, opaque at first, owing to the rising of a quantity of white porous scum, known by the name of *sandiver*, or *glass gall*. This substance has engaged a good deal of the attention of scientific men. It appears to be a confused mass, consisting of all the salts contained in common alkalies, which readily melt at a somewhat less heat than glass, and, being naturally very volatile, and having little, if any, affinity for silex, do not unite in the composition. When laded out and cooled, it forms a white crumbly mass, sometimes quite white, and at others brown and foul, and strongly saline, but not very uniform in its composition, being sometimes very bitter, which is probably owing to the sulphate of potash. Glass gall is very volatile in a strong fire, so that it is constantly dispersing from the surface of the glass in a dense vapour, which very powerfully corrodes the top of the crucible in its passage. If the fusion were continued a sufficient length of time, the whole might be dispersed in this way; but it is generally skimmed off with iron ladles, to be sold to the metal refiners, to whom it is very valuable as a flux. Some of the alkali itself is also dissipated by the continuance of the fire, partly before it can unite with the silex, and partly from the glass after vitrification, to which the corrosion of the pots must in some measure be owing; it unites also in some measure with the glass gall, which renders it slightly deliquescent. An abundance of glass gall is one of the greatest inconveniences that a glass-maker can meet with, as it requires a considerable time and a very strong heat before the whole can be dissipated; and if the glass be wrought before it is thoroughly purged of this material, it will be full of bubbles, unsound, and of a cloudy appearance. Glass made from potash is more likely to suffer from this impurity than the soda glasses, being harder and not so thin as the others, and the glass gall does not so readily dissipate in the fire.

There is another heterogeneous substance also called *sandiver*, which sometimes is found at the bottom of the pots, and is taken out when the whole is worked up. The nature of this is very different, from the other, consisting apparently of a vitrified mass of arsenic and other impurities.

As the heat in the furnace is continued, the glass gradually becomes more flexible, dense, and less brittle, the glass gall is at last entirely dissipated, and the vapours which it occasioned are no longer to be perceived. The glass is now full of minute specks and bubbles, which the heat causes to expand and burst at the top, till at last it refines beautifully clear, transparent, and colourless, as may be seen by the samples which are taken out by an iron rod and cooled. This latter part of the process, from the cessation of the

Mechanical Processes.

Manufac-
tures.

vapour of the glass gall, and its thorough removal, to the time when the glass is thoroughly free from bubbles, is called refining.

The fusion of the glass is now complete, but of much too thin a consistence to be wrought; it is therefore required to be cooled down, which is done by stopping the draught of the furnace at that part where the crucible is placed. The furnace is now re-opened by removing the clay already mentioned, and the operations of the glass-blower may be commenced.

When cooled to the heat proper for being wrought, the glass has lost its perfect fluidity, being of a consistent and tenacious mass, soft enough to yield to the slightest external pressure, yet capable of being bent, pulled, and fashioned into all imaginable shapes, without cracking or parting with its tenuity; so that if in this state it be stretched or drawn out it will preserve the form of a solid fibre, constantly decreasing in diameter, and will not separate until reduced to a minute filament. When no longer heated to redness, it becomes rigid, brittle, and transparent. During the whole time employed in working a pot of glass, which varies from five to twenty hours, and is sometimes even longer, its consistence should be maintained as nearly as possible at the same point; and to succeed in this considerable attention on the part of the workmen is required.

Furnaces.

(691.) *Furnaces.*—In consequence of the intense heat employed in the fusion of glass, the construction and materials of the furnace are subjects requiring considerable attention, not only with a view of rendering it capable of giving the requisite heat, but to construct it of such materials as will bear great heat for a length of time without destruction. The chief material, both in the walls of the furnace and in the pots, is clay, which is mixed with a proportion of sand; the relative quantity of the two depending on the quality of the materials. In general, a fine stiff clay will require about two-thirds the quantity of sand to bring it to such a consistence that it will work easily, dry into a compact mass, and resist the action of the fire for a length of time. The addition of too much sand renders it fusible, and liable to vitrify and separate from the walls by the action of the heat for a length of time; it is therefore advisable to use as little sand as possible, consistently with the proper working of the material.

Glass pots.

(692.) *Glass pots.*—Still greater attention is required in selecting the proper materials for the glass pots, as these have to withstand for a considerable length of time, not only the constant action of a fierce fire, but also the solvent power of the glass itself, with the variety of powerful fluxes in full vitrification. The pots, therefore, being made of earth, the material of them must necessarily be gradually dissolving, and hence, besides the property of difficult fusibility, earth of considerable purity is required; so that a small admixture of it with the glass may not injure its quality.

They are made commonly with five parts of the best Stourbridge fine clay, and one part of old broken crucibles, ground to powder for that purpose. Great nicety is required in mixing these materials, and in working them together, in order that every particle of air may be driven out, the presence of which would by its expansion in the furnace endanger the breaking of the pots. The clay is kneaded by the workmen, who tread it with their naked feet, turning it over from time to time, so that every part is equally acted upon. Attempts have

been made to effect this by Machinery, but they appear not to have been attended with success.

Mechanical
Processes.

When the material is sufficiently worked, it is formed into the pots, and left for several months, in order that the clay may be dried equally throughout the substance: and any small fissures, formed by unequal shrinking of the material, closed up by gently beating with a mallet. They are afterwards heated very gradually to a red heat, in a small oven made for the purpose; and, being kept for a considerable time, are removed while still hot to the furnace, and soldered down in their place by fine clay. A still further shrinking takes place in the glass furnace, for which reason they are left to stand empty for a few days before the gross materials are admitted. They last upon an average about a year, and generally have to be changed two or three times during the continuance of the furnace.

The manner of arranging the pots in the furnace will be understood from fig. 1 and 2, pl. 1. which represent a section and ground plan of an eight-pot furnace for flint glass. It consists of two parts, A A, B B, one within the other, of which the interior one is flat, and the exterior of considerable altitude, terminating in a high chimney: the only connection between the domes is by the flues G G, which are situated one on each side of the crucibles, so that they receive the whole body of the flame as it passes from the fire-place to the exterior dome, and thence to the chimney. The shape of the pots C C, &c. is peculiar, being of a circular figure at bottom, and furnished with a projecting part or spout at the top. They are situated at equal distances round the furnace, between the pillars or piers E E, &c., which support the exterior dome, and in such a position that while the body of the crucible is within side, and exposed to the most intense heat of the flame, the front or projecting part is level with the exterior of the furnace. By this means, while the contents of the crucibles are accessible to the workman from the outside, they are shut out from the interior of the furnace and immediate action of the flames, which would be very liable, from occasionally parts falling in, to injure the quality of the glass. The fire-place is supplied with fuel by the openings a a, in two of the piers, which are however so weakened by it that additional pillars are necessary at that part for the support of the exterior dome.

Construction of a
glass furnace.
Pl. 1.
Fig. 1, 2.

For the construction of furnaces for crown and other kinds of glass which are similar in principle to the above, although their shape is in some measure varied, we must refer the reader to Loysel's *Art de la Verrierie*, where a particular account of these furnaces is given; we proceed to describe the manipulations of the manufacture.

Manufacture of Flint Glass.

(693.) The aid which the improvements in Machinery have afforded the greater proportion of our manufactures has not at present been extended to that of glass, and in this respect it may fall short in interest if compared with some others; there is, however, a degree of skill and sleight-of-hand displayed by the workman in the different processes in forming the great variety of utensils made of this material, which is certainly not excelled in any other Manufacture, and which universally excites the astonishment and admiration of those who behold them.

Flint-glass
manufac-
ture.

In consequence of the superior brilliancy of flint glass

Manufac-
tures.

in comparison with the other kinds, it is most commonly employed for all the ornamental utensils which adorn the tables of the wealthy, for which purposes it possesses an additional advantageous property, *i. e.* of possessing when at the working heat a degree of tenacity and ductility not to be found in any substance in nature.

Although the shapes given to glass vessels are so very varied and numerous, they are produced by a few simple instruments; and almost every article, of whatever figure it may be, is shaped out of a hollow globe formed by blowing.

Glass-blow-
ing.

(694.) The most useful implement in this process is an iron tube, about four or five feet long. To form a globe this tube is dipped into the pot containing the glass at the working heat, and turned about until a sufficient quantity adheres to it for the purpose intended. It is then held near the ground, by which the glass lengthens by its own weight, and assumes the shape of a pear. The workman then blows strongly through the tube, and his breath penetrating the centre of the red hot mass extends it into a hollow globe of uniform thickness. It must be blown out as large as intended, and the force of the breath kept upon it for a few seconds, till it stiffens by cooling, otherwise it would sink again by the pressure of the external air. This operation produces a hollow globe, adhering to the neck of the iron rod, out of which an immense variety of forms may be produced.

Mode of
making
glass drink-
ing utensils,

We cannot here pretend to give an adequate idea of the ease and dexterity with which this beautiful substance is formed from a globe into the numerous shapes given to decanters, wine-glasses, &c. The following description of the mode of making the common tumbler, which is perhaps the most simple table utensil, will however illustrate in some measure the manner in which the manufacture is conducted.

A hollow globe with a short neck being first blown on the iron rod, as above mentioned, it is transferred to a short solid iron rod by an assistant, who dips the end of the rod into a glass pot, and brings it out with a little melted glass adhering to it, which he immediately places at the bottom of the globe at the part directly opposite the neck: to this it firmly unites, so that the globe becomes cemented on this second rod, by means of the melted glass. The workman then wets a small piece of iron with his mouth, and lays it on the neck of the globe, which is still extremely hot, and thus causes it to crack all round in a second or two, so that with a slight pull it comes off, leaving the globe open at the neck, and attached to the second rod on the opposite side. The globe is now again softened by holding it for a few seconds over the mouth of the glass pot, and a portion of it is cut from the open end by a pair of shears, leaving the remainder in the form of a cup. The workman when at work usually sits upon a kind of arm-chair, the arms of which slope forwards, and are covered with a flat, smooth, iron plate; so that by resting the rod on both arms of his seat, and twisting it backwards and forwards, the hot glass at the end is made to revolve like clay in a potter's lathe. The workman takes in his right hand an iron instrument, in some measure resembling a pair of sugar-tongs, being connected at top by a flat elastic spring, but having the prong nearly of a round figure. By this simple instrument he may give the glass while in motion an infinite number of shapes with a degree of facility that can scarcely be conceived by a person who has not witnessed the opera-

tion. If the glass have cooled below the working heat, previous to the final shape and smoothing being completed, it must be again heated by holding it at the mouth of the crucible, and continuing the operation; if not completed by the second heating, it must be re-heated, and so on alternately until the vessel is of the required shape, when it is separated from the iron rod by wetting it at the point of attachment. This last operation leaves that burr or roughness which is seen at the bottom of all glass unless taken off by grinding.

Mechanical
Processes.

Decanters are rather a more complicated piece of workmanship, the shape being given from the globe while it still remains on the iron tube. The flat or upper part of the instrument is used for this purpose, which, by alternately pressing against the glass in the parts required to be flat, and blowing through the tube, the body of the decanter is soon brought to the proposed shape. A workman now brings the iron rod with a piece of melted glass, which he attaches concentrically with the bottom of the decanter; the other workman at the same time applies the cold iron rod moistened with water to the other end, and the glass vessel is by this means almost instantaneously transferred to the iron rod. The decanter has now to be again heated, in order to form the mouth part, which is done by first smoothing the end very truly, by introducing the prong end of the tool, and bringing it into a position nearly at right angles with the axis of the decanter. The rings which are formed on all decanters are still to be added, which is done by the addition of fresh glass. An assistant workman brings an iron rod, provided with the required quantity of melted glass, which he applies at the part where the ring is intended to be made, and the workman at the same time turning the decanter, a ring of melted glass is caused to encircle it, which is made of the required shape by a gauge contained in the inner part of one of the prongs of the above-mentioned tool. In the same way the remaining rings are put on, which being done, the decanter is again introduced into the mouth of a glass pot, and brought up to a considerable heat, in order that the rings may be well fused with the body of the metal. The decanter is now complete, with respect to shape, but is again submitted to the turning operation as it cools, to be rendered smooth and perfectly true in every part.

The manner in which all other round glass vessels are formed is similar to that described above, so that it is unnecessary to enter into any further description of them. Vessels which are not of a round figure cannot, however, be accomplished by these means: it is then necessary to have a mould, in which the glass is placed while it is blown, which causes it to take any impression with the most complete precision.

(695.) *Annealing.*—Another important process is *Annealing*, required before the glass vessel is fit for use, *viz.* that of *annealing*, without which it will always be liable to fly by the least change of heat and cold, by the smallest scratch, or even without any apparent external cause. This process consists in allowing the glass to cool very gradually in a low chamber built for the purpose, near the furnace, which is sufficiently hot at one end to keep the glass in a state approaching to softness, but gradually diminishing in heat towards the further end; so that being introduced at one end, and pushed forward as new articles are brought up, it arrives by degrees at a cooler part of the oven, and finally at the other extremity, where the temperature does not exceed that

Manufac-
tures.

of the surrounding atmosphere, and whence the vessels are removed for use, the disposition to fracture above described being entirely removed, if the operation has been continued for a sufficient length of time, which with common articles is generally about twenty-four hours.

The extreme fragility of unannealed glass is very remarkable and difficult to account for; but is supposed to be owing to the forcible contraction of the outer part by sudden cooling, while the inner portion is still soft and semifluid; so that there is an inequality of strain throughout the fibres, and as glass is extremely elastic as well as brittle, any force which tears asunder a portion of the strained part communicates a strong and sudden impulse over the whole mass. This theory in some measure is borne out by the very interesting experimental toys termed the Bologna phial, and the Rupert's drop. The former is simply a phial, of any form whatever, made of any kind of glass, but much thicker at bottom than at top, which is cooled immediately without annealing. Being made rather stout it will bear a smart blow with a wooden mallet or any blunt instrument, or the concussion of a leaden bullet dropped into it from a considerable height, without injury; but if any sharp body however small, such as a grain of sand or a small piece of a gun flint, be dropped in only from a few inches height, the bottom cracks all round, just above the thickest part, and drops off; and the same effect happens if the bottom be scratched with any hard body. The effect is not always immediate, as the phial will remain sometimes for a few minutes and sometimes for hours, and then suddenly give way.

Bologna
phial.

Rupert's
drop.

The Rupert's drop is simply a small solid lump of glass, poured when red hot into cold water, which causes it to assume a round figure, elongated into a kind of tail. This solid lump will bear very considerable resistance on the rounded end without injury, and is altogether extremely tough; but when the least portion of the thin end is broken off, the whole bursts with a smart explosion, and into a countless number of fragments, as small as fine sand. It is a very common trick, played upon those unacquainted with the toy, to give one in their hand, and then to break off the end, when to their astonishment and alarm a great explosion takes place; but the fragments are so small that no injury is done to the hand, otherwise than a sharp stinging sensation, which, however, from being so totally unexpected, is very frequently magnified by the astonished experimenter into a more serious affair.

The force of the explosion is said to be so great, that if one of these drops be placed in a phial or tall glass filled with water, and the end broken off with a pair of pincers, the vessel will be infallibly broken. The stoutest wine or beer bottle would not be strong enough to withstand the shock.

This very singular effect can only be owing to some permanent and very strong inequality of pressure; for if the drops are heated and allowed to cool of themselves, this property of bursting is entirely lost. The brittleness of the Bologna phial is also removed by again heating and cooling slowly.

Glass
cutting.

(696.) *Cutting glass.*—The glass utensils which contribute so greatly to the embellishment of tables and saloons owe much of their richness and brilliancy to the elaborate manner in which they are cut. The implements employed by the glass-cutter, although of necessity numerous, owing to the great variety of work which

he has to execute, yet partake of the same simplicity which is observable throughout the various processes of this Manufacture.

Mechanical
Processes.

The cutting instruments employed are of a circular figure, and are attached to an axle, which may be made to revolve either by an assistant, or by the power of a steam engine or horse-mill. The workman presses the glass vessel against the wheel, and by that means produces an impression in the glass of a figure, depending upon that of the cutting wheel. The materials employed in the formation of these cutting implements are both wrought and cast iron, Yorkshire stone, and willow wood. Wrought iron is used only for cuttings of such narrow dimensions that they cannot be made by cast iron. Iron wheels are used in the commencement of the operation, with sand, which causes them to cut very rapidly into the glass. They leave the work very rough, so that a great deal of grinding and polishing is afterwards required, and they are for this reason not made use of in executing fine work, the grinding being performed entirely by the Yorkshire stone. Over each wheel a small keg or conical vessel is placed, the opening of which is so situated that a due quantity of water is supplied regularly to it, and when the iron wheel is used, this vessel is furnished with a quantity of sand, and water being admitted into it from another vessel, a regular supply of moistened sand is delivered upon the face of the wheel.

After the glass has been reduced pretty nearly to the required figure by the iron wheel and sand, the former is removed, and a wheel of Yorkshire stone substituted in its place, and by this the asperity and roughness are worn down, and the cutting is reduced to the exact figure required, so that no further process is necessary, except that of polishing. This operation is performed upon wooden wheels, the surfaces of which are covered with pumice or rotten stone, and afterwards with putty powder, to give the high degree of polish requisite for finishing.

(697.) *Glass pressing.*—In consequence of the great amount of labour required to cut glass elaborately, and the consequent expense attending it, several methods of ornamenting as a substitute have been attempted, and although they fall far behind the cut glass in point of brilliancy, yet from their greater cheapness they are very much to be recommended. We refer more particularly to an invention which has recently been the subject of a patent. The pattern is given by placing a quantity of melted glass within an external metallic mould of the required form, and then bringing down an interior one, of the shape and dimensions of the interior of the required utensil, and pressing the melted glass between the two. The two parts of the mould are connected together by means of a hinge, and the upper one is provided with a long handle, which acts as a lever for imparting the requisite pressure. The lower section is composed of two pieces, which, being opened, the glass can be removed from the mould immediately after formation.

Glass press-
ing.

An immense quantity of glass is to be seen in our shops manufactured in this manner, more particularly tumblers: they can always be distinguished from those which have been blown and cut by the bottom being of a regular figure.

(698.) *Watch glass.*—Although the most extensive application of flint glass is in the fabrication of vessels for the table, there are many others of considerable importance to which it is adapted, among which may be

Watch
glasses.

Manufac-
tures.

enumerated watch glasses. They are made from hollow globes about 8 inches in diameter, weighing about 12 ounces. The spheres are then divided into a number of pieces by a workman, who takes the globe in his lap, and with a piece of heated wire or tobacco-pipe traces lines upon it in the places where he desires it to be separated, and immediately after wets it, which causes the glass to divide along the lines traced by the wire with the utmost precision. For tracing, a piece of tobacco-pipe is preferred, because it retains for a longer time a sufficient degree of heat.

The pieces into which the globe is divided have of course many angular irregularities, which are removed by a pair of scissors. Before the watch glasses are completed it is yet necessary to give each segment an additional degree of convexity, which is done by first heating, in order to render them soft, and then, by an appropriate instrument, pressing in the edges of the glass towards the centre, which is by this means made to rise in corresponding proportion. The edges are then ground evenly off, and the watch glasses are ready for sale.

Lunette
glass.

Lunette glasses are made from a pear-shaped figure, having the larger end farthest from the extremity of the rod, of the size required for the watch glass, and the requisite flatness is given by pressing the end while soft upon any smooth level surface. These are necessarily much higher in price than the watch glasses commonly used; both because they are made to contain a greater weight of glass, and because only one being cut from each pear-like figure the labour expended in the Manufacture is proportionally greater.

Manufacture of Flint Glass for Optical Purposes.

Manufac-
ture of flint
glass for
optical pur-
poses.

(699.) The general transparency, hardness, unchangeable nature, and varied refractive and dispersive powers, Dr. Harding remarks in his *Memoir* on this subject, render glass a most important agent in the hands of the Philosopher engaged in investigating the nature and properties of Light, but when he desires to apply it according to the laws he has discovered in the construction of perfect instruments, and especially of the achromatic telescope, it is found liable to certain imperfections, not essentially existing, but almost always involved during its preparation, and fatal to its use. These are so important and difficult to be avoided, that Science is frequently stopped in her progress by them; a fact fully proved by the circumstance, that Mr. Dollond, one of our first opticians, has not been able to obtain a disc of flint glass of English manufacture, of four and a half inches in diameter, fit for a telescope, within the last five years, or a similar disc of five inches in diameter within the last ten years.

The properties of transparency, hardness, and a certain degree of refractive power, may be easily obtained, but there is one condition essential in all delicate cases of application, which is not so readily fulfilled, that is to say, perfectly homogeneous composition and structure. Although every part of the glass may be as good as possible, yet without this condition they do not act in uniformity with each other; the rays of Light are deflected from the course they ought to pursue, and the piece of glass becomes useless. The streaks, striæ, veins, or tails which are seen within glass, otherwise perfectly good, result from a want of this quality; they are visible only, because they bend the rays of Light which pass through them from their rectilinear course,

and are constructed of a glass having a greater or smaller refractive power than the neighbouring parts. Mechanical
Processes.

These difficulties, as has been before observed, have induced several men eminent in Science to labour earnestly for years together, in hopes of surmounting them. Among these, Guinand has been one of the most successful, having produced discs perfectly homogeneous, of larger diameter than had previously been done. This persevering and ingenious man was the son of a joiner, residing in a remote village among the mountains of Neufchatel in Switzerland, and was himself brought up as a cabinet-maker. He became afterwards a clock-maker, which business was sufficiently lucrative to afford him the means of indulging his scientific and mechanical taste. He was led to the science of Optics, by accidentally seeing an English refracting telescope; and afterwards hearing of the difficulty of obtaining good flint glass, and that a prize had been offered for the discovery of a perfect process, he commenced a set of experiments on the subject, which has been attended with results highly beneficial to the Science of Optics, and which, considering the limited means possessed, entitle him to a high rank as a man of Science.

The ingredients and compositions which he employed appear to have been kept a secret, but the following facts relating to some of his operations, which appeared in the 38th Number of the *Quarterly Journal of Science*, are highly deserving of insertion in this place.

After considerable difficulties in obtaining proper furnaces and crucibles, he at length obtained a block of glass of about two hundred weight, which after having sawed in a vertical direction, he polished on one of the sections, in order to examine what had taken place during fusion, and the following were the appearances:

On the upper surface of the vitreous matter, there were many little semi-globules, which had the appearance of drops of water, terminating by a thread or little tube of greater or less depth, at the extremity of which there was a small spherical bulb. This appearance was owing to these drops and tubes consisting of a denser kind of glass than the rest of the block. In another part there arose from the bottom of the crucible other cylinders or tubes, terminating also in a kind of swelling or bulb, which had a hollow appearance from being formed of a substance less dense than the rest of the glass; and lastly here and there were seen specks ending with a tail or train of a substance also less dense than the rest of the mass in which they floated; these, on account of their appearance, Guinand denominated comets.

The following is M. Guinand's explanation of these effects. Having often seen on the surface of his glass small globules of lead, he supposed that, from some cause or other, particles of the lead which composed his vitreous matter separate from it, and appear on the surface in their metallic state; which becoming again oxidized by contact with the air, or re-calcined after being resuscitated, (to use his own expressions,) they combine with the vitreous matter on which they rest, and thus cause, in the place where they occur, that glass to be of greater density which appears on the surface in the form of drops. The specific gravity of this substance draws it to the bottom of the crucible; but in descending more or less slowly according to the temperature of the furnace, it leaves in its passage a train which occasions those threads of glass possessing a stronger refraction. Having reached the bottom, this vitreous matter, in some degree saturated with minium, being a powerful

Guinand's
theory of
the cause of
the imper-
fections in
glass.

Manufactures.

substance, attacks the material of the crucible, and forms with it a vitreous compound, of an inferior density to the mass, which ascending in consequence of its specific levity, produces those cylinders or tubes formed of a less refractive glass. Lastly, when this solvent, by melting the surface of the crucibles, especially that of the bottom, has detached from it a grain of sand or baked clay, this half-molten grain rises and floats in the mass in an oblique direction, because being still attached to a part of the vitreous matter which it has produced, it is not actuated on all its points to ascend with equal rapidity.

Whatever may be thought of this explanation, the original cause of the non-homogeneity of strongly refractive glass being once ascertained, the question of the means of remedying it still remained to be solved; and it was here in particular that M. Guinand had great obstacles to surmount; so that the sacrifices and exertions which he had previously made were trifling, compared with those which he afterwards underwent for the purpose of removing these various defects, and of rendering his glass homogeneous.

After many expensive trials, M. Guinand was so fortunate as to obtain a glass, of which some parts were perfectly homogeneous, and therefore destitute of those striæ or threads from which flint glass is so rarely found free. He reflected on the different circumstances which in this experiment might have contributed to so happy a result, so that in subsequent attempts he obtained blocks of glass possessing larger portions of homogeneous substance, and at length is said to have arrived at a certainty of obtaining, in the fusion of from two to four hundred weight of glass, at least one half of that substance perfectly free from defect.

When M. Guinand first obtained blocks containing portions of good glass, his practice was to separate them; by sawing the blocks into sections that were horizontal or perpendicular to their axis, then polishing the sections, he selected the portions adapted to his purpose, and returned the others to the crucible; but independently of the tediousness of the labour, and the waste occasioned by sawing, this process was attended with the great disadvantage of not cutting the finest parts of the glass in the manner best calculated to obtain discs as large as possible, for frequently the most homogeneous parts were thus divided; but a fortunate accident, of which he availed himself with his usual adroitness, conducted him to a process more simple and better suited to the attainment of his object.

One day, while his men were carrying a block of this glass on a hand barrow to a small water saw-mill which he had established at the fall of the Doubs, at the distance of half a league from his abode, the mass slipped from the bearers, and rolling to the bottom of a steep and rocky declivity, was broken into several pieces; M. Guinand was at first grieved at this mishap, but having selected those fragments which appeared to be perfectly free from defect, he succeeded in softening them in circular moulds in such a manner, that on cooling he obtained discs that were afterwards fit for working. Henceforward he adhered to this method; and he also contrived a mode of cleaving his glass while cooling, so that the fractures would follow the most faulty parts.

When flaws occurred in large pieces of glass, he removed them by cleaving the pieces with wedges, and melted them again in moulds which gave them the form of discs, generally taking sufficient to allow a little of the glass to project beyond one of the points of the edge,

so that the opticians who work them might be enabled to use that portion of glass in making a prism, which should give them the best measure of the refractive power, and thus obviate the necessity of cutting the lens. The refraction of M. Guinand's glass varies almost at every casting, while, on the other hand, each of the castings is of such homogeneity, that the refractive force of two pieces taken indifferently, one from the top and the other from the bottom of the crucible, is absolutely the same. This mode of fabricating glass from pieces rough and shapeless in the first instance, and afterwards remolten into discs, renders the process of M. Guinand absolutely different from that of other glass-founders, who proceed either by casting or blowing.

When the discs obtained by this process are still defective, as sometimes happens, and especially with those of large dimensions, M. Guinand obviates the defects by means of the wheel; (*roulette*;) then by softening them again, the vitreous matter expands and fills up the hollows which have been made; if, after polishing, he finds them still defective, he repeats the process until the discs are as perfect as he could wish. By these means he has often succeeded in soldering pieces of glass, which have left no trace of their separation. At first these pieces were only cemented, and there was frequently even air or sand between the united surfaces; in these cases he cut along the line of junction a small semicylindrical groove, in order that the vitreous matter while melting might fill it, not by flowing from its edges to the bottom, but by raising the bottom itself; and by repeating this operation a sufficient number of times, he declares that he has succeeded in effacing all traces of junction.

(700.) We have now to speak of the experiments of Dr. Faraday, whose labours in the promotion of this object, so important to Science in this instance as well as in many others, will always call forth the gratitude of his countrymen.

The proportions of ingredients made use of by Dr. Faraday, in the composition of his glass, have already been described in Article 679; it is only therefore necessary at present to speak of the apparatus and processes employed by him, upon which so materially depend the success of the operation.

He employed two furnaces, the first of which was termed the *rough glass furnace*, and consisted of an iron box 30 inches long, 14 wide, and $8\frac{1}{2}$ deep, which formed the interior. It was entirely open at the top, and in part at the bottom, where a fire grate was placed; it was provided with a common iron furnace door in front, and at the back with a funnel pipe to connect it with a powerful flue. The sides of the box and such parts of the bottom as were not appropriated to the fire grate were lined with fire-stone. The grate was 12 inches long by 8 wide, and the part above was closed by a fire tube two inches thick and 12 square, which resting on the edges of the lining formed the part intended for the coal fire, leaving it $5\frac{1}{2}$ inches in depth from the covering tube to the grate. The other part was covered by an iron plate, which, resting upon the edges of the lining, inclosed a space for the reception of the crucibles which was provided with holes for the purpose. The crucibles were of porcelain biscuit, perfectly pure and white, 5 inches high outside, $3\frac{1}{2}$ inches diameter at top, and $3\frac{1}{4}$ at bottom, and as thin as possible, of the finest and most refractory kind of ware, baked at a high temperature. The covers to the crucibles were evaporating basins about $4\frac{1}{2}$ inches in diameter, which were slung

Mechanical Processes.

Experiments of Dr. Faraday.

Furnace.

Manufac-
tures.

with their edges downwards by a piece of platina wire, which, being bent in the middle at an angle and stretched across the outside of the basin, had its ends formed so as to engage the opposite edges. The extremity of an iron rod, passed under the loop thus formed, served to remove the cover from place to place.

Process of
manufac-
ture.

The heat was not altogether given by flame; but, while coal was used in the fire place, coke was applied between the crucibles, and arranged throughout the unoccupied holes. A portion of the rough materials properly cleaned and prepared were introduced into the crucible, and a low heat kept in the furnace, so that they were by degrees converted into glass. Before the first charge was entirely melted, a second was put in, and sometimes a third, according to the quantity of glass present, and the soundness of the crucible. When all is fused, the temperature is allowed to rise, but not too much, lest action upon the crucible to a serious extent might occur; the glass is then well agitated and mixed by a platina rake or stirrer. Finally, the glass is either transferred by a platina ladle into trays roughly turned up out of old platina foil, or into a clean, deep, white earthenware vessel, containing much distilled water. In the latter case it was obtained in a divided state, and when drained was dried on the sand bath and put up in clean bottles.

The rough glass, thus prepared, is in the next operation to be converted into an annealed and finished plate, which is effected by casting it in a platina vessel of the required dimensions, formed out of a platina plate by turning up the sides. Dr. Faraday states, that it is of importance that it should be formed out of the best platina, rolled very carefully, so that no holes occur, and of such thickness that one inch should weigh as much as 17.5 grains.

Finishing
furnace.

The platina vessel is placed in the second furnace, termed the *finishing furnace*, which is constructed principally of brick work, and in the shape of a parallelopiped, containing a fire chamber 25 inches long, and 12 $\frac{1}{4}$ broad. The fire place is at one end, and the course of the flame and smoke is directed from that to the other by a flue which passes under the chamber. A trough made of rolled iron occupies the lower part of the ash pit, which, being preserved full of water, is sustained at a boiling temperature by the radiation of the heat and hot ashes which fall into it, and causes the passage of steam beneath the bars, which Mr. Faraday states to have found of considerable utility in keeping the bars clear of clinkers, which would otherwise impede the free passage of the air.

In addition to the fire place, the furnace is provided with an opening beneath the chamber, in which coke is used, and which acts both as a furnace and a flue.

The platina trough being carefully adjusted in its position in the chamber by pieces of tile, &c., and filled with a proper quantity of rough glass, and covered over, a fire was lighted in the furnace, and properly attended to, that the temperature might be properly sustained. The glass may with propriety be examined once early in the experiment, for the purpose of ascertaining that the tray and its contents are safe; but it is usually left for six, or eight, or a greater number of hours, that the whole may fuse, the temperature rise, and the bubbles escape.

There are two conditions of the finished glass, each of great importance, which it is the object of the process to obtain in this state of the substance. One, the most

essential, is the absence of all striæ or irregularities of composition; the other the absence of even the most minute bubbles. The first is attained by agitation and perfect mixture of the whole; the latter principally by a state of repose, so that the means required to be successful on each point are directly opposed to each. Were the glass incapable of change, by the long-continued action of heat, it would be easy to render it uniform by stirring, and then to leave it in a quiescent state, until the bubbles had disappeared; but from the length of time which it required to liberate bubbles even from small pieces of glass, without stirring, Dr. Faraday was induced to conclude that the evolution of gaseous or vaporous matter had not ceased upon the first fusion of the materials, but that the glass itself when highly heated continued to evolve small portions for some time. It occurred to him that its formation might be hastened and final separation advanced by mixing some extraneous and insoluble substance with the glass, which should act as a nucleus.

The substance which he resorted to for this purpose was spongy platina, this being a body solid at high temperatures, uninfluenced by the glass, easily reduced to powder, and likely to retain its finely divided condition during the operation, and he found it to assist powerfully in the evolution and separation of the bubbles, and afterwards to sink so completely to the bottom, that not a particle remained suspended in the mass.

The best time of introducing the platina, and the times of stirring, were points upon which Dr. Faraday was not fully satisfied, but, in the greater number of the experiments, it was sprinkled over the surface of the well fused and highly heated glass at the period of the first stirring. This method had the advantage of bringing the assistant substance into contact with the glass, when the latter was highly disposed to throw off its gaseous matter, and to allow of thorough mixture; but it also causes the addition of fresh glass, after the concoction of the materials has been proceeding several hours, in consequence of the platina being prepared by diffusing it with pulverized glass.

On other occasions, the prepared mixture of platina and glass has been introduced into the tray at the period when it was charged with the due quantity of rough glass, and before the application of fire. Particular attention was then paid to its general diffusion throughout the mass, and on these occasions its action commenced the moment the glass in contact with it was fluid. Faraday states, that he is inclined to believe that the latter will ultimately prove to be the better method, both from the greater length of time the platina acts, and for the facility and convenience of its introduction.

We must not conclude this section of the article, without adding to the names of those who have laboured at the solution of the same practical problem that of the late lamented Fraunhofer, the chief of the celebrated establishment of Berne, whose experiments were attended with considerable success; but we regret to say that the ingredients and processes which he employed are not known, and the Art has probably died with him.

Articles manufactured by the Blow-pipe.

(701.) Thermometer and barometer tubes, and a variety of ingenious toys, and other small articles of glass, are made by a lamp and blow-pipe. The usual apparatus

Glass arti-
cles manu-
factured
with the
blow-pipe.

Mechanical
Processes.

Spongy
platina em-
ployed as a
nucleus.

Fraun-
hofer.

Manufactures.

of the glass-blower is very simple, consisting of a sol table, at the bottom of which is placed a double bellows with a foot-board, that the artist may work with his foot and keep both hands at liberty. A pipe proceeds from the bellows to conduct the blast to the lamp, which consists of a large bundle of cotton threads lying in a tin vessel of a horse-shoe shape, and fed with lumps of tallow heaped up beside it, which, being from time to time drawn forward into the flame, keep up the combustion. The blast-pipe is brought in such a direction as to drive the flame in a contrary direction to that in which the artist sits, so that he is not in any degree incommoded by it. The remainder of the apparatus of the glass-blower consists of a few simple iron tools, such as small forceps, files, &c., and an assortment of glass tubes of different bores and thicknesses, made at the glass-house by pulling out rather suddenly a bottle of blown glass while quite soft.

The flame when in full vigour is a jet of about four inches long, of a blunt spear-head shape, which, at the extremity, is of a pale yellow, and, nearer the wick, of a blue colour. The tubes are heated gradually by being held first in the yellow and then in the blue, which is the hottest part of the flame: the blast is then put on, which very soon brings the glass to the state of fusion. The flame is strong enough to bring to a very white-red heat a solid mass of glass about as big as a child's marble, or even larger, which, when blown out very thin, will make a bulb of the capacity of full three ounces, which is nearly the extent of the power of the common lamp blowing.

Thermometer tubes.

To form each thermometer tube, they are first sealed hermetically at one end, by simply holding one in the flame a little time, and then slowly turning round, which will cause the end to melt, and, by falling in, to close the cavity. As an additional quantity of glass is required to form the bulb, an iron instrument is pressed upon the end while hot, which will consolidate it and shorten it a little. The open end of the tube must then be placed to the lips without loss of time, and by blowing steadily the lump of glass will immediately open into a bulb, the size of which will depend upon the continuance and strength of the breath.

In sealing a tube hermetically, when a bulb is not required, it is necessary to reduce the quantity of glass at the end, or the button (the term given to the end of the tube) will be too clumsy, and, from its thickness, be in danger of breaking from cooling. This is done by applying a piece of another tube of nearly the same size, to stick firmly to it, and then, by heating it for some distance at the end, and drawing the tubes in contrary directions from each other, the thickness of the tube, as it approaches the end, will be so diminished that, when sealed, an equal thickness will be preserved throughout.

Barometer tubes.

Barometer tubes require to be bored, which is done, in tubes of narrow bore, by simply holding them in the weaker part of the flame, so as to soften about an inch or two of the length, and then bending them slowly by the hand into the required shape. But if the tube be wide and the glass thin, this way of bending entirely destroys the cylindrical form of the bore, at the bent part making a double flattening. To avoid this, the tube is first sealed up at one end, and, while bending, a person blows steadily into the open end, and with sufficient strength to counteract the falling in of the sides of the bending portion, and keep the bore cylindrical. The closed end is

then cut off, by making a deep scratch with a three-cornered file, and then breaking the tube by a smart pull in such a direction that the scratched part will be outermost, which will separate it, in general with great accuracy, at the required point.

Mechanical Processes.

Glass, when in a fused state, is so tenacious, that it may be spun out, by means of the blow-pipe, into threads of such fineness, they may be wound almost like common thread without breaking; in fact, this material is so perfectly ductile, that the expert glass-blower may form, not only a great variety of interesting and beautiful toys, but little implements useful in Chemistry, and even for domestic purposes.

Manufacture of Flat Glass.

(702.) This material, although not so brilliant as flint glass, is much more perfect, and can be obtained in much larger masses, free from striæ, or other irregularities of composition. All mirrors, looking-glasses, &c., are made of this glass, and many other articles too large to be manufactured in flint glass. It is also useful for optical purposes, being employed with the flint glass to form object glasses.

Plate glass manufacture.

The greater number of plates of glass are executed by blowing, but as this operation is performed in the hand, plates exceeding a certain weight cannot be manufactured in this manner, and, in consequence, for those of larger dimensions, the operation of casting is had recourse to. The process for making blown plate is as follows.

When the contents of the crucibles are thoroughly refined, and brought to the proper state for working, a workman goes into the ash-pit, and very carefully closes up the openings between the bars of the grate with a composition, consisting of clay and cut straw, to prevent the introduction of any air into the furnace through the fire-place, which would endanger the rupture of the pots, and produce too rapid a cooling of the furnace. The metal is thus allowed to cool gradually down to the working state, which generally takes nine or ten hours after the orifice has been closed. It is now modelled in a manner similar to that used in flint glass, already described. A workman dips an iron pipe into the crucible, and having taken out a little of the fused glass upon the point of the iron, waits a moment till it has adhered; he then dips it again, and rolls another portion round the former, which he repeats until he finds he has taken up enough for his purpose. He then, by blowing down, produces a globe which, by repeated heating and blowing, he enlarges to a diameter of 12 or 14 inches, or more, according to the size of the intended glass plate.

Manufacture of blown plates.

It is now necessary to convert this globe into a cylinder, which the workman effects by giving to the rod to which the soft glass is attached the motion of a pendulum. It is then heated afresh at the mouth of the furnace; a hole is punched with an iron chisel and mallet in the centre of that end of the cylinder which is furthest off the working rod. The orifice which has been thus made is afterwards widened by an instrument kept for the purpose; and then, a pair of shears being introduced, a slit is made in the cylinder of glass, extending to one-half its length. It being necessary, however, that the cylindrical form should for the present be preserved, another workman applies a temporary rib of glass, which has been previously attached to a working rod, across that end of the cylinder which has

Manufac-
tures.

thus been cut open; and when this is done the other rod is detached, in order to allow of that end of the cylinder being also heated, opened, and slit up with shears. The whole of the cylinder being thus divided, the pontel is detached from it, and the glass is carried to the spreading oven, where it is laid upon an elevated floor covered with a thick stratum of sand, to prevent adhesion of the glass in its softened state. In a few minutes it is pushed to an adjoining apartment, where it is quickly placed in a vertical position to anneal. The annealing kiln or oven having been thus filled with the plates of glass, each standing on its edge, the doors and chimney are closed and carefully luted with clay, to prevent the possibility of any cold air entering the chamber for the space of twelve or fourteen days; after which the lutings are gradually loosened, and the glass is removed to an open part of the glass-house, to attain, by degrees, the temperature of the surrounding atmosphere. When an hour or two has elapsed, these plates may be carried with safety to the cutting room, where they are turned round the edges with a diamond, or by other means, to prepare them for the operation of grinding.

Grinding.

(703.) For the operation of grinding, the plates of glass are bedded in a horizontal position in plaster of Paris upon a table or frame made either of freestone or wood. Another plate being then reversed and suspended over the first, the material employed in grinding their surfaces is introduced between the two, and they are made to rub steadily and evenly upon each other by means of Machinery put in motion by the steam engine. When one side of the plate is done, the plaster which cemented it is picked off, the plate turned, and the opposite side ground in the same manner. The process lasts about three days, and, towards the end, the pressure is increased by loading the upper plates with flat stones of different thicknesses. It was formerly usual to employ river sand as the grinding material, a circumstance which entailed considerable loss and waste upon the manufacturer: the glass which was ground off, and which usually amounts to one-half the weight of the plates as they are cast, being thus mixed with this material, was rendered unfit for any purpose of glass-making, except that of making black bottles. Mr. Parkes calculated that the loss of real glass at the London plate house could not be less than two tons per week. This led to a patent being taken out by Mr. Heard, late chemical manager at the works at East Smithfield, for a means of saving the whole of this refuse, which consisted in grinding the plates with pure flint instead of river sand. Three or four tons of the prepared flint employed by Mr. Heard are equal in effect to twenty tons of sand; the work is done in much less time, and the abraded matter, instead of being a cumbrous and useless mass, is admirably adapted to the purposes of the manufactory, and capable of yielding a considerable profit.

Smoothing.

When the glass is by this means reduced to a plane surface, the next process is that of smoothing, which may indeed be considered a continuation of that of grinding, the object being that of reducing the inequalities of the surface, and preparing it for the last operation of polishing.

Preparation
of the
emery

Emery is the substance employed in smoothing; it is prepared by putting a considerable quantity into a vessel containing water, and stirring it about until the whole is mechanically mixed with the water. The emery being insoluble in water, if the mixture is allowed to rest for a sufficient time, the whole subsides in layers, the coarsest and heaviest particles sinking first,

and so on successively, until the very finest particles range themselves as the upper stratum. Previously to this, however, and while these fine grains are still suspended in the water, it is poured into a separate vessel, and the emery there allowed to settle. A fresh supply of water is poured into the first vessel, the contents of which are again violently agitated, and allowed partially to subside as before, but for a shorter time, so that emery of a second degree of fineness is separated. This operation is repeated, in order to obtain powder having four different degrees of fineness; the deposits are then separately dried upon a stove to a proper consistence for making them up into small balls, in which state they are delivered to the workmen. In smoothing the glass, the coarsest emery is of course used first, substituting that of a greater degree of fineness as the work proceeds.

Mechanical
Processes.

(704.) The completing process is that of polishing, which is performed by a substance termed *crocus*, a brown-red oxide of iron, found remaining in the retorts after the distillation of the acid from sulphate of iron. The instrument in polishing is a piece of wood covered with several folds of woollen cloth, each fold having between it some carded wool, so that the whole forms a tolerably hard but elastic cushion, which is furnished with a handle for the convenience of the workman.

This operation is performed by hand. The plate being imbedded in plaster upon the table, in the manner already described, and the polishing instrument wetted by means of a brush, and covered with *crocus*, the workman performs the operation by rubbing the cushion backwards and forwards over the surface of the plate, commencing at the corner, and completing each part as he proceeds. Considerable practical skill and dexterity are required to give a uniform degree of polish all over the plate, and the finishing touches require to be given with care and judgment.

The plate is turned after one side is polished, the previously polished side being provided with a coating of red *crocus*, as the white plaster would otherwise hinder the workman from forming an accurate judgment of his progress in this second operation. When the workman is satisfied with the result of his labour on this second surface, the plate is taken from the table, and, being cleaned, is laid, each side in its turn, upon a dark-blue or black cloth, which, as it admits only a moderate light, exhibits any parts which may be less elaborately polished; these must be retouched by a small cushion. When the polishing has been satisfactorily completed, the plates are washed with water and removed to the warehouse for sale.

(705.) *Cast plates.*—The manufactory at Ravenhead, which, we believe, is the only important one for cast plates in this Country, has, ever since its first establishment in the year 1771, been carried on with such a degree of secrecy that little is known of the processes and operations employed in making the best plate glass. Mr. Parkes, in his Work entitled *Chemical Essays*, gives much useful information, which he states himself to have received by various channels, and we avail ourselves of the same for the following account of these works. When the glass is thoroughly refined, it is filled into a vessel termed the cistern, which is previously heated to a temperature equal to that of the glass. A copper ladle, ten or twelve inches in diameter, fixed to an iron handle, is plunged into the glass pot and brought up filled with melted glass, which is transferred to the cistern; the ladle during this transference is sup-

Manufac-
tory at
Ravenhead.

Manufac-
tures.

ported on a strong iron rest placed under its bottom and held by two other workmen, which is necessary to prevent the bending and giving way of the red hot copper under the weight of fluid glass which it contains. When, by successive lading, the cistern is filled, it is suffered to remain for some hours in the furnace, that the air-bubbles occasioned by this disturbance may have time to rise and disperse.

It is then removed to the casting table, which consists of a cast-iron plate fifteen feet long, nine wide, and six inches thick, supported upon strong pillars, and furnished with ribs of iron at the sides and end, which are moveable and can be adjusted nearer together or further asunder according to the size of the plate intended to be cast. These were originally made of copper, but in consequence of this metal being found liable to crack from the sudden access of heat that accompanies the pouring over of such a torrent of melted glass, the British Plate Glass Company determined to make a trial of iron, and had a table made of the dimensions above described, which has fully answered the intended purpose, having, during several years of constant use, stood uninjured throughout all the violent and sudden alterations of temperature to which it is exposed. The table is so massive, weighing nearly fourteen tons, that it became necessary to construct a carriage purposely for its conveyance from the iron foundry to the glasshouse. It is supported on casters for the convenience of readily moving it towards the mouth of the different annealing ovens.

The foundry in Ravenhead, where this table is used, is said to be the largest room under one roof in this Kingdom; it is 339 feet long, 155 feet wide, and proportionally lofty. Westminster Hall, to which the superiority in this respect is commonly ascribed, is smaller; its length being 300 and its breadth only 100 feet. The melting furnaces, which are arranged down the centre, occupy about one-third of the whole area of the apartment, and the annealing ovens are placed in two rows, one on each side of the foundry, and occupy the greatest proportion of the side walls, each being 16 feet wide and 40 feet deep, and their floors being level with the surface of the casting table, the plates of glass may be deposited in them immediately after they are cast with little difficulty and without delay.

Operation
of casting.

(706.) When, from the inspection of the samples taken out, the melted glass is found to be in the exact state that experience has pointed out as being most favourable for its flowing readily and equally, the door of the furnace is opened and the cistern removed to the casting table, which is previously heated by hot ashes and wiped quite clean. Any scum which may have collected on the surface of the melted glass is then carefully removed by a copper instrument, as the mixture of any foreign substance with it would infallibly spoil the beauty of the plate. The cistern is then hoisted up by tackle or a crane, and swung so as to be over the upper end of the casting table, and then overset, which causes a thick flood of melted glass to flow and spread in every direction upon the table; the surface of the glass, while still in the semifluid state, is then made quite smooth and uniform, by passing over it a heavy copper roller, turned very true in a lathe. This roller rests upon ribs on the table, and consequently reduces the glass to a plane surface, having a thickness equal to the height of the ribs from the surface of the table, and width equal to the distance between the ribs, but the length depends upon

VOL. VII.

the quantity of metal in the cistern. Should the quantity of metal exceed that required for the full dimensions of the table, the metal rib is removed from the lower part, and the surplus glass is received in a vessel of water placed under the extreme end for the purpose; but if the glass falls short of the required quantity, the moveable rib is shifted up the table, to give a square termination to the plate, in order that no unnecessary waste should occur. This operation is said to be very interesting; the spectacle of such a large body of glass poured at once upon a metallic table of great magnitude is very grand: the variety of colours also which the plate exhibits immediately after the roller has passed over it renders this an operation very splendid and interesting.

The number of workmen required for the whole process is at least twenty, each of whom has his particular duty assigned him. From the time the cistern is removed from the furnace to the completion of the casting, by the glass becoming hardened, the apartment must be kept as free as possible from disturbance; even the opening and shutting of a door might, by setting the air in motion, disturb the surface of the glass, and thus impair the value of the plate.

As soon as the plates become fixed by cooling, they are thrust by main strength off the table, and gradually slipped into the annealing oven immediately contiguous, where they are treated like the smaller plates already described, except in the circumstance of their being spread out one by one in a horizontal position, instead of being piled on their edges as before mentioned.

When the plates have remained about twelve or fifteen days in the oven, the process of annealing is complete, and, after a strict examination by the inspector to see if each is free from flaws, nothing further remains to be done than the grinding, smoothing, and polishing, which operations are performed in the same manner as those on the smaller plates already described.

The great size to which founders are now enabled to get these plates is very astonishing. The proprietors of the above Company have announced that they have on sale plates of the enormous size of 6 feet by 12 feet each, equal to 72 feet of surface, which, to obtain perfectly true and free from flaws, may be considered the effect of great skill and ingenuity. From the liability to holes and other flaws, which render it necessary to reject numerous plates, the expense of the larger ones increases in a great ratio, as will be seen from the following list of the prices of the Company.

Dimensions.	Prices.		
	£.	s.	d.
60 inches by 30 inches . . .	10	10	1
60 40	16	3	5
60 50	22	10	5
70 50	28	7	8
80 50	34	14	10
100 50	48	9	0
100 60	63	15	0
100 70	80	8	2
100 80	98	4	10
132 84	200	8	0
160 80	246	15	4

Crown Glass.

(707.) This is the description of material of which the greater part of glass for windows is composed, although some of the larger sort, such as those used in shop win-

Mechanica
Processes.

Manufac-
tures.

dows, are too heavy to be executed in the manner in which this material is manufactured, and are in consequence made of plate glass by casting.

The commencement of the process is the same as in blowing flint and plate glass; viz. the workman dips into the crucible of melted metal, reduced to the proper heat for working, until a sufficient quantity is collected to form a plate of the intended dimensions, which is commonly $9\frac{1}{2}$ pounds; this is effected by three successive dippings, and, by long practice, he will gather the same weight within two or three ounces. He then alternately blows down the tube, and rolls the expanded glass on a flat iron table, till it has got the figure of a flask, and is nearly of equal thickness throughout: it is then flattened at bottom, which completes the first part of the operation. An assistant now dips a solid rod into the pot, and, taking out a little glass on the end of it, applies it at the centre of the flattened bottom of the flask.

Having by means of this lump of fresh glass attached a new working iron, it becomes necessary to withdraw the former, which is effected in the usual manner, by a workman, who wets the end of a small iron utensil with a little cold water; with this he touches the glass at the point, where it produces a crack, so that by a sharp stroke the old instrument may be detached from it, which leaves a hole in the piece of glass about two inches in diameter.

A new working iron being thus attached to the glass, exactly at the opposite point to that where the former one adhered, the workman carries it by the present or new rod to the flasking furnace, and holds it for a few minutes at a small opening, termed the nose hole, turning it gently in his hand all the time. The small hole in the furnace is contrived merely for the purpose of heating that part of the glass to which the cold water had been applied. By this means it is put in a proper condition to be introduced into the larger opening of the furnace, where it is heated by degrees until the mass becomes sufficiently ductile for further working. He then begins to turn it quicker and quicker, holding it the whole time at the mouth of the oven, till it becomes so much softened, that, merely by the centrifugal force communicated by the rapid motion of the instrument to which it is attached, the whole mass opens itself by degrees, extending further and further till it suddenly assumes the shape of one immense circular sheet of glass 40 or 50 inches in diameter, and of one uniform thickness.

This operation is called *flushing*. There is exhibited in the performance of it a great degree of dexterity, and altogether, from the unexpected changes of shape which take place from the different manœuvres of the workman, it excites a greater degree of interest to the visitor than perhaps any manufacture in this Kingdom.

The sheet or table, when thus completed, is laid by a fork upon a bed of ashes, and the rod cut from it by means of a pair of shears, a knot or burr being left behind. It is then set up in the annealing arch, where it is kept for four hours at a dull red heat, and then thirty-six hours more to cool. The diameter of the sheet is 4 feet, and the working off by each pot produces about 180 sheets. For the convenience of packing, each table is divided as equally as possible, consistently with having the whole of the burr in one of the pieces. The thickness of the glass is nearly equal in every part, except in a circle extending a few inches round the burr. In cutting it up for use the burr is left in the middle of a square pane, which is employed only in glazing cellars and outhouses.

Although, as we have just stated, these lumps of glass are only used for glazing in places where strength is more an object than beauty, yet the glass in such pieces is frequently so perfect as to be worked into the crown lenses of telescopes of the smaller kind. It is singular, after the mode of manufacture above described, that any glass of this kind should be fit for optical purposes. It appears, however, that our first English opticians generally prefer it to plate glass, although the slight tinge of green which it always has necessarily intercepts a certain portion of light; the image, however, of a star formed from an object glass of flint and crown, is seen with a more defined disc than from those made of flint and plate, thus fully compensating the astronomer for any trifling loss of light he may sustain from the colour.

(708.) *Broad glass*.—It is evident that there is a natural limit to the size of the tables made, as above described, it not being possible for a man to blow a flask much larger than is required to form a table of the usual dimensions, and the size of the pane of glass that can be cut from such a table is further limited by the knot which occupies its centre. But for picture frames, and for the larger kind of window glass, plates larger than can be cut out from any table are wanted. Such plates are called broad or spread glass, or German sheet, whether made here or imported from Germany, whence they were originally derived.

The largest tables manufactured are 5 feet in diameter, and the largest square that can be cut from such plates is 36 inches by 24; but broad glass may be had 42 by 28 inches, by first blowing it into a flask, then taking off the flask by means of the solid rod, as already described, and forming it into a cylinder. It is then taken from the rod in the shape of a hollow cylinder, open at both ends, and heated in order to be separated throughout the length by a pair of shears, it is then expanded on a hot plate, and made even by pressure.

(709.) *Annealing*.—In annealing crown and broad glass considerable nicety is required in regulating the temperature of the annealing arch, as a small excess of heat would render the plates so soft that they would bend out of the perpendicular and be much injured. On the contrary, if the furnace be not hot enough, there is great danger of the plates flying in pieces; but if this should not happen, this defect would inevitably be discovered by the glazier, because glass imperfectly annealed is operated upon by the diamond with great difficulty, and it is almost impossible to cut it with exactness.

Crown glass is sold according to its quality under four different denominations; firsts, seconds, thirds, and fourths, at considerable difference of price, that of the fourth's quality yielding to the manufacturer scarcely one half of the first. These variations arise partly from the goodness of the materials, but are considered to be principally owing to the want of sufficient care in maintaining the necessary degree of heat in the furnace. If this is suffered to fall, it is difficult, owing to glass being a bad conductor of heat, to raise it to the former degree. In the operations of the glass-house it does not often happen that beyond one-third of the quantity made is of the first quality, the largest proportions of the produce being composed of seconds and thirds.

(710.) *Bottle glass*.—We have still to mention the manufacture of bottle glass, which, however, differs so little from the methods employed in forming bottles in flint glass, that little requires to be said on the subject. The glass is collected on an iron tube and blown into a globe, from

Mechanical
Processes.

Broad
glass.

Annealing.

Bottle
glass.

Manufactures.

which it is fashioned, by means of a few iron tools of different shapes, into the article required, excepting half-pint, pint, and quart bottles, which are blown in a case either of iron or brass. All these goods are likewise removed while quite hot to a furnace to undergo the usual process of annealing to render them fit for use.

Bottle glass being made without lead will bear a greater heat without melting, and is therefore more fit for utensils employed in chemical processes, where any heat is required; its chief use is, however, for common bottles, where the quality of transparency is not essential, and the consumption for this purpose is so great that the number of hands employed in the manufacture exceeds the total number employed in fabricating the remaining descriptions of glass.

On coloured Glasses.

Coloured glasses.

(711.) Although, in the uses to which glass is usually applied, the transparency and whiteness are properties much to be desired, and upon the perfect attainment of which the chief attention of the manufacturer is bestowed, yet there are many uses of this material where the colour is much desired, as in ornaments where the beauty is chiefly depending on the degree of colour. This department of the Art is carried on to a great extent, and though much of the management remains a secret, a good deal of valuable matter has been made public by the labours of Neri, Kunchel, Margraaf, Fontanieu, and other practical chemists; the following short account of which we hope will prove interesting.

The metallic oxides are the substances usually employed to produce colours on glass, and are capable, when well prepared, of giving a degree of richness and beauty of tint which is scarcely excelled by natural gems. In the manufacture of these articles the composition of glass differs from any we have previously described, and is a subject upon which a great deal of difficulty arises, as it is necessary to unite the qualities of great purity, lustre, and hardness, together with a sufficient degree of fusibility to melt at such a heat that the oxides will not be decomposed, which qualities, from the circumstance of the oxide of lead, which gives the greatest lustre, also rendering them soft, it is evidently difficult to combine in the same material.

We do not conceive it necessary to enter into a description of the various compositions employed in forming artificial gems, but refer the reader, desirous of such information, to the articles Glass in the *Encyclopædias* of Dr Brewster and Dr Lardner, and to Aikin's *Chemical Dictionary*. We content ourselves with giving the following account of the properties of the salts and oxides of some of the principal metals, for which we are indebted to the last-mentioned work.

Colouring properties of gold.

Of gold.—This metal in a state of minute division and oxidated has long been celebrated for giving glass a most exquisite purplish-red, resembling the ruby, and almost equalling it in beauty. It is both the most expensive and most splendid of all the artificial gems or coloured glasses, but in the management it seems to be very difficult to obtain complete and uniform success, which is principally owing, it is supposed, to the great tendency of gold to assume the reguline state from mere heat, by any carbonaceous vapour, or by hydrogen.

The most celebrated and common preparation of gold for giving a purple to glass and porcelain is the

purple precipitate of Cassius, or gold precipitated from its nitro-muriatic solution, together with the oxide of tin. The usual way of making it is to dilute very largely a solution of gold in aqua-regia, and adding to it drop by drop a very dilute nitro-muriate of tin. The liquor immediately becomes of a purplish-red colour, and by standing a precipitate of some varieties of shade slowly subsides. A similar precipitate also takes place with the nitro-muriate of gold, and the pale muriate of tin, and also with greater certainty by immersing a stick of tin in a dilute solution of gold. This substance is an intimate mixture of the oxides of tin and gold, but the precise state of oxygenation of the tin is not well known, nor its exact use, as it is certainly not essential to produce a purple tinge in glass; many preparations of gold produce it in which not an atom of tin enters.

Another preparation of this metal used in glass colours is the fulminating gold produced by precipitating this metal from its nitro-muriatic solution by ammonia. This preparation will explode most violently when raised to a somewhat less heat than that required to melt tin, or even by moderate friction; but if kept for some time at a much lower temperature, being previously mixed with fixed alkali, it loses its fulminating property, and may be used with safety. A more manageable preparation of gold is the precipitate from the nitro-muriate, by the carbonate of potash, which is a brown-red or yellowish powder, and is not fulminating, provided the solution of gold be made with the muriatic acid, and not muriate of ammonia; it being the presence of ammonia which gives the fulminating property. For fine carmines this carbonated oxide of gold, as well as the decomposed fulminating gold, are mixed with lunar cornea, and then with the proper quantity of a saline flux, in which nitre and borax usually enter. The colouring power of these simple oxides of gold is nearly twelve times as strong as that of the purple precipitate, which is another proof that tin does not of itself add to the body of the colour.

Of silver.—All the oxides of silver give a yellow to vitrescent substances, which appear to be very pure and beautiful, but it is not often used in coloured glasses on account of the ease with which it is destroyed by too much heat. It seems to be chiefly employed for colouring porcelain and enamel, where the eye of the artist can always be on his work, and the heat is lower and much more manageable. In the latter case, the oxide of silver is generally mixed with a small quantity of alumina. The phosphate of silver, formed by adding the nitrate of silver to the phosphate of soda, is also employed.

Of iron.—The shades of colour produced by the oxides of iron are very numerous. A small portion of iron, fully vitrified with a large body of glass, gives different shades of green and yellow, and it is to this substance that the colour of the bottle-green glass seems to be owing. A larger dose of it gives a yellow, after thorough vitrification, and a still larger gives a brownish-black, which seems to be only a yellow very much concentrated, since this latter colour is again produced by diluting the brownish-black with a greater quantity of uncoloured glass. The oxides of iron also produce a red upon enamel and porcelain, but this is supposed to be owing to its being suspended in the glass flux in a state of extreme division, for when by raising the heat a complete fusion of the oxide is produced, the colour turns to yellow. This change is ingeniously prevented by combining the oxide previously with alumina, by mixing the

Mechanical Processes.

Manufac-
tures.

sulphate of iron and alumina together in solution, and precipitating both together by carbonate of potash.

A great many different preparations of iron have been used, but there does not seem any direct reason for the preference, as they will all, when fully vitrified, produce a yellow or brown, according to the dose. Brongniart asserts that the presence of oxide of lead singularly disposes the perfect oxide of iron to lose its red or rose-colour, and it is used for that purpose in enamelling.

Iron appears to be the natural colouring matter of the sapphire, lapis lazuli, and some other blue minerals, and was employed by the Ancients to give a blue colour to glass, as was proved by the analysis of some of the ancient blue enamels; but the Art now seems to be entirely lost.

Copper.

Of copper.—All the oxides and carbonate oxides of copper produce a fine green when thoroughly vitrified with any kind of glass or flux. There does not seem to be much reason for the preference of any one particular preparation, but those commonly used are the carbonated oxide produced by adding a carbonated alkali to the sulphate of copper, and copper oxidated and calcined simply by heat and the action of the air. This metal may, however, be made to give a carmine red (or, mixed with iron, a full deep red) by adding to glass containing it a quantity of tartar when in complete fusion, and working off almost immediately; a greater continuance of heat, however, restores the green colour. The oxide of copper is often mixed with manganese and iron to produce a full-bodied black glass; when combined with three times its weight of alumina in a strong heat, it runs into an opaque red enamel.

Lead.

Of lead.—This oxide is capable of giving a yellow, but is seldom used directly as a colour, on account of requiring the enormous proportion of three-fourths of the glass to give a yellow of any intensity, and this would give a compound extremely soft, and which would act very powerfully on the crucibles.

Antimony.

Of antimony.—The perfect oxide of this metal gives a full yellow to glass, both alone and in compound colours, where yellow is a necessary ingredient.

Manga-
nese.

Of manganese.—The proper colour given by this oxide is, when not in contact with carbonaceous matter, purplish-red, rather muddy when in a full body, but still very beautiful. The colour is totally destroyed by all the arsenical salts, as we have before described, and therefore arsenic in any form should be avoided when manganese is used as a colouring matter. This oxide is the principal ingredient in most of the black glasses.

Cobalt.

Of cobalt.—The colour given by the oxide of this metal is a fine blue, which is unalterable in any fire, and succeeds with any flux. Cobalt is also used for some of the finer blacks, mixed with manganese and iron, and with yellow of antimony and lead it composes a green.

Chrome

Of chrome.—This metal, which is the natural colouring matter of the ruby and emerald, would be a most valuable one if it could be procured in any quantity. It has been found to give a fine red, and also a most beautiful green to glass, but its great scarcity has prevented its frequent use.

The oxides of tungsten, nickel, and some other metals, are capable of giving colours to glass, but as their application is limited, and use consequently unfrequent, we have omitted to speak of them here. In consequence of having already exceeded the extent assigned for the present article, we must also omit any description of the valuable receipts and processes given by Kunchel, Fon-

tanieu, and other practical chemists, for the formation of particular colours, and content ourselves with referring the reader to the excellent treatise on glass in Aikin's *Chemical Essays*.

Mechanical
Processes.

Enamelling

(712.) The art of enamelling consists in the application of a thin coating of vitrified matter upon a polished metallic plate. The vitrified substances employed are of three kinds, transparent, semitransparent, and opaque, but the latter are the more commonly employed, and those which the term enamel is generally considered to signify. It is of itself a delicate white, but is susceptible of the most beautiful tints by the mixture of various metallic oxides in the composition; its natural whiteness and beautiful texture also render it particularly calculated as a ground for painting, and a degree of delicacy and richness of colour can be given on this substance not to be excelled by any other means.

Enamel-
ling.

The Art of enamelling is of great antiquity, having been practised by the Egyptians, to compose ornaments for the envelopes of their mummies. We have also various antiquities which prove that it was known to the Greeks, Romans, Saxons, and other ancient nations, but it appears to have been made use of by them only for ornamental purposes. Since the invention of watches and clocks, this manufacture has, however, become of greater importance, from being so well calculated, from its permanency and beautiful whiteness, as a material for the faces.

Antiquity
of the Art.

The composition of white enamels does not differ much from that of common glass, except in the addition of oxide of tin; the exact proportion of the ingredients is, however, a matter of some importance, in the first place to render it of a clear fine white, so nearly opaque as to be translucent only at the edges: and secondly, sufficiently fusible to run into a kind of paste which will extend freely and uniformly over the surface of the metal without fully melting into a thin glass.

Composition of enamels.—The following are the directions given by Clouet for composition of white enamel. Mix 100 parts of pure lead with from 20 to 25 of the best tin, and bring them to a low red heat in an open vessel, which causes them to burn very rapidly and oxidate on the surface; the crusts of oxide must be rubbed off as they are formed, until the whole is thoroughly calcined. A quantity of sand must be calcined with a fourth of its weight of salt, and 100 parts of the resulting substance mixed with 100 of the above oxide, and 25 or 30 of common salt, will form a composition which, by the application of a proper degree of heat, will form a good enamel. If more fusibility is wanted, the dose of oxide is increased, and that of the sand diminished, the quantity of common salt remaining the same. The sand required for this process, Clouet states, should not be of the common sort, but a micaceous sand, in which the mica forms about one-fourth of the mixture.

Composi-
tion of
enamels.

Neri, in his valuable Treatise on glass making, has given proportions of the ingredients, which vary considerably from the above, but which have been confirmed by Kunchel and other practical chemists. His directions are as follow: Calcine 30 parts of lead with 33 of tin, and take of this calcined mixed oxide 50 pounds, an equal quantity of powdered flints, (prepared by being thrown into cold water when red hot and ground

Manufac-
tures.

to powder,) and 8 ounces of salt of tartar, and melt the whole in a strong fire kept up for 10 hours. This composition produces a material of a grey-white, which is that most commonly employed for opaque enamels. To render it quite white, 48 grains of manganese must be added for every 6 pounds, and the mixture melted in a clear fire, then cooled by throwing cold water upon it, remelted, again cooled by water, and so on for several times, which will render the enamel perfectly white and fine.

Metals used
as enamel
grounds.

Metals used as grounds for enamelling.—Enamels, as before stated, are usually laid upon a metal ground, although in some cases it is used in substance, to form ornamental vessels, figures, vases, &c., by running it into moulds immediately from the pots in which it is melted; this kind of enamelling is, however, now very rarely practised. The only metals suited to the purposes of the enamels are gold and copper, all other metals being either too fusible to endure the action of the fire, not having sufficient affinity for enamel to cause it to adhere and remain attached, or exert some chemical action on it, which destroys its whiteness and beauty. Gold is unquestionably the best substance to enamel on, and it is almost always used for transparent enamels from the richness of tinge which it produces, but in the more extensive application of this art, *i.e.*, in clock and watch making, fine copper is always employed. The use of silver has been attempted, and although it has the requisite property of being unalterable by the heat necessary to be employed, yet it is found to act so powerfully on the oxides contained in the melted glass, as thereby materially to impair the colour of the article, so that its use is found in most cases inadmissible.

Enamelling Watch Dial Plates.

Watch dial
plates.

(713.) The enamels used in this extensive branch of the Art are of two kinds, *viz.*, the glass enamel, the composition of which has been described above, and the hard, or Venetian enamel, which is the most beautiful substance; but the greater care required in the manufacture renders the plates considerably more expensive, and it is for that reason not so frequently adopted as the former.

Pl. I.

Fig. 3, 4, 5,
&c.

The copper employed in this manufacture is received in thin sheets prepared for the purpose, and, after being heated, is formed by means of a die to the required convexity, and cut so that the edges extend a little beyond those of the die; these edges are afterwards rubbed down by means of a blunt tool, and by that means form a rim round the plate. An opening is made at the centre, and at any part where a second or other hand may be required, by piercing a hole from the inside or concave side of the plate, which causes a slight rim or edge to stand up above the upper surface. The tool by which this is done is shown at fig. 6. of plate I. These edges are afterwards reduced by a fine file so as to be raised the exact thickness of the intended coat of enamel. The plate, after being cleaned by immersion in water, acidulated with sulphuric acid or aquafortis, and rubbing the surface over with a scratch brush, is prepared to receive the first coating of enamel.

Preparation
of the
enamel.

The enamel is received in the shape of lumps, which are first broken down with a hammer, and then ground to a powder in an agate mortar to a degree of fineness equal to that of fine sand. It is then washed in very clear water, and, when the heavier parts have subsided,

Mechanical
Processes.

the remaining milky-looking fluid is poured off and left to settle in a separate vessel. This operation is several times repeated, so that the powder may be divided in separate portions, having different degrees of fineness.

It is necessary that both sides of the copper have a coating of enamel, to prevent the plate being drawn out of its true shape by the unequal shrinking of this substance and of the metal. For this kind of work, the counter enamel is only about half the thickness on the concave as on the convex side, but for flat plates the thickness is required to be the same on both sides. The enamel is first spread on the concave side of the plate by means of a spatula, and the plate is then laid between the folds of a cloth or napkin, in order to absorb a portion of the water, and again rendered perfectly smooth and even by the spatula. The plate being now inverted and fixed firmly in a horizontal position, a quantity of enamel is spread on the upper surface, level with the rims at the circumference and centre, and a cloth applied so as to absorb the superfluous water. The plate is then carefully examined, and the enamel rendered perfectly smooth and even by means of the spatula.

(714.) *Firing.*—It is now prepared for the operation of firing, which is performed in furnaces termed the *muffle furnaces*, of which a representation is given in plate I. fig. 3. 4. B B are two pieces of brickwork, on which rest the arch C, which covers the ash or coal pit; from each side of these piers project three bricks, E, fig. 3, which support the hearth or iron plate F; another plate of cast iron lies beneath this, which serves for the bottom of the furnace, but which is not seen in the section, and G H H are the interior sides of the furnace, which are supported upon this plate, and contained in brickwork which extends on each side over the piers. The brickwork is bound together by the iron bar I, which also serves as a support to the brickwork over the furnace.

When the fire is made up for use, the muffle is placed in the furnace, with one end resting on the iron support, as shown at L, and the other kept level with the front by putting a piece of coke under each side. The muffle is shown separately at fig. 9. The space on each side is then to be filled with small pieces of coke, and at the upper part and back of the muffle small coke must likewise be placed until it reaches about halfway up the end. A solid piece of coke must then be selected large enough to cover the end of the muffle, and upon this a second piece is placed as a supply when the first is burnt away. The fire is now lighted by introducing red hot charcoal in the space left under the muffle, and by drawing out the damper the fuel will soon be lighted all over, and the heat rapidly raised.

The method of arranging the dial plate in the muffle is represented in fig. 11, where A is the dial, which is supported upon a ring, B B, composed of pipe-maker's clay, and the two rest upon a circular flat piece of firestone or Stourbridge clay, C C, about the eighth of an inch thick. The part marked D is termed the *turner*, which is made of a spherical figure, so that the whole apparatus may be turned round upon it in any position by a pair of tongs for the purpose, shown at fig. 10, to cause the enamel to be equally well fused in every part of the plate. The planch is placed in the furnace, and, when it is heated to a white heat, withdrawn, and the dial plate and ring being arranged as shown in the figure, the whole is placed upon the turner under the muffle, and kept in constant motion by a pair of tongs,

Manufactures.

until it assumes a uniform surface, when it is withdrawn and allowed gradually to cool.

It will be found that a considerable depression has been produced in the enamel by the act of fusion, so that the edge and eye are considerably above the surface. This deficiency it is the office of the second coat of enamel to supply. When the work is cooled, the second process is commenced by removing the scale from the edges and eyes by means of a fine-grained Lancashire file or a smooth grey stone, and, after being washed and dried, the plate is securely fixed down, and a second layer of enamel gently spread with a quill, and prepared for firing by the napkin and spatula as before, and the operation of firing repeated.

Polishing.

(714.) *Polishing.*—The plates, although perfectly bright and glossy, are uneven on the surface, which has to be rendered smooth, and the glossiness again produced, before they are complete. They are taken separately, and the fine edge worn off by a species of fine grey-stone till they are smooth and even, after which the eyes are rubbed down till the centre of each plate is even and square. The irregularities of the surface of the enamel are removed either by the rag-stone or grey-stone, with fine ground silver sand and water. This is done by an expert workman, who, by giving a circular motion to the plate, is enabled to grind it with a surprising degree of regularity, rendering it perfectly smooth, but the gloss is entirely removed. They are now well rubbed over with ground glass to remove the stains which have been left by the polishing stones, and, clean water being suffered to run upon them, they are wiped dry, and again placed upon the rings for firing. The heat of the furnace must be just sufficient to run the surface of the enamel, which will recover the glossiness destroyed by the polishing, and thus render complete the fabrication of the plate.

The coarser description of watch plates are made rather differently, and are termed *run-down plates*, and *run-down one coats*, the former of which are made by laying the enamel in sufficient quantity to form plates of the required thickness without putting on a second coat, by which great time is saved, but the same degree of regularity and neatness cannot be given as in the mode above described. The run-down one coats differ from these only in being completed by polishing.

Venetian or hard plates.

(715.) *Venetian or hard enamelling.*—In enamelling the Venetian or hard plates, the coppers and first coats are prepared in the same manner as the glass enamel, except that the layer is rather thinner. The hard enamel is ground down in steel mortars to a coarse grain, and exposed to the action of aquafortis or vitriol, in order to destroy any particles of iron which may have become mixed with, and which would infallibly destroy the beauty of the enamel. The powder is then carefully washed to remove the acid, and reduced to the necessary degree of fineness in an agate mortar, and spread over the copper with a quill in small quantities, and as evenly as possible; it is then alternately dried and smoothed by cloth and a spatula as before, and fired twice. The polishing of this enamel is done first by a very fine-grained Lancashire file or smooth piece of steel and silver sand; secondly, by fine blue-stone and sand; and thirdly, the blue-stone alone. With the latter, as great a degree as possible of polish should be given to the enamel, as the plate will then be finished in the third fire with a less degree of heat than would be otherwise wanted. Much attention must be used to prevent scratches, which

cannot be filled up by the fire without a greater heat than the enamel will bear. When the polishing is complete, the plate is carefully cleaned, and, should there be any specks discovered, they must be picked out with a sharp diamond, and the hollows filled up with enamel, and the plate exposed to a fourth firing. If the part where the enamel has been added is found raised above the general surface, from too large a quantity having been used, it must be smoothed by the blue-stone, and the plate submitted to a fifth firing.

Mechanical Processes.

Hard enamel plates are always considerably dearer than glass ones, from the greater labour and attention bestowed upon them, and the best watches are always made up with dials of this kind.

Clock Dial Plate Enamelling

(716.) The processes employed in this branch of the manufacture resemble in a great measure those we have already described; in consequence, however, of the much greater size of the plates, great care and attention are required to prevent them from warping and altering their shape by the heat of the furnace. The manipulations by which this is effected, termed *planishing*, form a very important and difficult process, and quite distinct from any employed in the watch plate enamelling.

Clock dial plates.

In consequence of the difficulty of preserving a large plate perfectly flat, from the unequal expansion of the metal, a slight curvature is given to it by means of large brass dies or a Machine adapted for the purpose. This Machine consists simply of an anvil bedded firmly in a strong oak block, the face of which is made concave and highly polished; above which is suspended a hammer or monkey, having the face made in a corresponding degree convex, and which is also highly polished. When the plate is prepared by cleaning and annealing, and the holes for the hands pierced by means of an iron punch, it is placed on the anvil and a blow given to it by the hammer, which reduces the unevenness and renders it of the required curvature. A strong and uneven spring will still remain, which has to be removed by a repetition of the operation, but previously, in consequence of the hardness and stiffness produced by the hammer, the process of annealing must be again resorted to, and the copper must be cleaned and pickled as before. It is customary also, after the plate has passed through the planishing Machine, to place it in a die and subject it to a number of blows by a wooden mallet all over the surface, which is found to render the spring more uniform from the edge to the centre. It is then annealed and subjected to the operation of the planishing Machine a second time, and the same operations are repeated three, four, and even as many as seven times, with large plates, or when the metal is not of good and regular texture.

Planishing

Upon the perfect manner of performing the operation of planishing greatly depends the beauty of the manufactured article, any irregularity in the surface of the plate being very painful to the eye, and the endeavour to correct it is generally attended with great danger of totally destroying the plate. When the planishing is properly performed, the copper will flap or bend into the curve when turned either side uppermost. It is then in a fit state for receiving the enamel, for which it is prepared by the usual process of pickling and attentive cleaning.

The enamel for clock dials is broken down in a steel mortar, and afterwards cleansed and ground in one of

Manufactures.

agate, in the same way as for watch plates, but the large quantity required renders the operation much more laborious and tedious; particularly as the hard description of enamel can only be used with complete certainty. The powder which arises in grinding, and floats in the water, termed the *washing*, is frequently employed for the backening of the plates. It is, however, very liable to blister in the fire, and thereby to cause the plate to cockle or alter its shape, and for these reasons, in manufacturing the best description of plates, the enamel in substance is always employed, which renders the success of the work much more certain.

Manner of laying on the enamel. Fig. 7, 8.

For putting on the enamel, the plate is placed upon a cloth, and the backening spread on carefully by means of a small bone or ivory spoon, fig. 7, and, when the whole surface is covered, the water is partially dried by a cloth, and the enamel laid even and smooth by a spatula, fig. 8; which operations are repeated until the surface is sufficiently even and dry; then the copper is turned, and the first coat laid upon the face in a similar manner. The work is then put upon a planch for firing in a situation near the furnace, or in holes termed annealing holes, that the moisture may be evaporated previous to its introduction into the muffle. The planches are from one quarter to three quarters of an inch in thickness, depending on the size of the plates, and are made either of fine fire-stone, or of a composition of Stourbridge clay, pipe-clay, and the remains of old planches, which are pounded together in an iron mortar, and passed through a sieve. The face of the planch is either flat or rubbed into a similar curve to that of the coppers, and, before the work is placed upon it, a slight covering of whiting is sifted on to prevent the enamel from sticking to the planch when in the act of fusion.

When the muffle is sufficiently hot, the planch and copper are carefully removed from the annealing hole by means of iron prongs, which are slid beneath the planch and plated in the furnace, and when the firing is complete, which may readily be determined by the appearance of the surface of the plate, it is again removed to the annealing hole, that the cooling may be as gradual as possible. The gradual cooling is necessary to prevent the enamel cracking on the surface, which would be otherwise likely to occur from being set in the cold air, and thereby prevented from gradually adjusting itself to the contraction of the metal.

The application of the second coating is an exact repetition of the same process; we have therefore only to speak now of the polishing, in which the operation differs considerably from that employed for watch faces. The plates when cold are carefully fixed upon a bed of wet sand, so that no vacancy or hollow occurs beneath the plate, or are imbedded in a similar way with sand upon wet flannel twice or thrice doubled. When thus prepared, the surface is worn even by means of silver sand passed through a sieve, and polishing stones formed of flint pebbles, and ground to a surface. The sand is used with water, and the operation is performed by giving the polishing stone a quick circular motion over every part of the plate, till the surface is evenly reduced, which is known by the glossiness being entirely worn off; this occupies from half an hour to an hour, and sometimes more, according to the size and previous evenness of the plate. Sometimes the polishing is accelerated by using in the commencement pieces of lead and iron, but they are always finished by the polishing, which is necessary to remove the blackness or

stain produced by the metals. The plates are now made perfectly clean by fine enamel ground over the surface of each by a small mull or polishing stone, and the surface of the plate wiped with a cloth, which is employed instead of washing by water, in order that the loose enamel that may be collected in any little holes in the plates may not be removed; the plates are thus without any further trouble rendered smooth by the next operation of fusing; should any holes or specks remain after this, they must be removed and repaired in the same way as we have described for watch plates.

In preparing plates for enamel painters, after the polishing is completed, a coating of a substance termed a *flux* is laid on previous to the last firing, after which the plate is sometimes again polished, but the enamelling colours are more frequently put on in the state it leaves the furnace.

Transparent enamelling.—The operations for transparent enamels are similar to those we have already described, but as the work is generally of a more minute kind, a greater degree of delicacy is required in the operations. Watch cases are commonly enamelled upon gold as well as most of the superior articles of ornament, and the surface is frequently engraved into different figures and compartments before the enamel is laid on, by which means the work assumes a beautiful variegated appearance through the vitreous coating. In enamelling the backs and edges of watch cases, &c., quince water is frequently used as the medium by which the enamels are laid on, in consequence of its possessing a more adhesive and retentive quality than common water, and thus better prevents the enamel flowing by its gravity from its proper situation, and destroying its figure. When enamels of different colours are intended to be employed in the same article, which is frequently the case in ornamental work, small edges or prominent lines are left in the substance of the metal, which are polished with the enamel and reduced to the same equality of surface.

Gunpowder Works.

(717.) *History of the invention of gunpowder.*—Before we enter upon a description of the processes followed in the manufacture of gunpowder, it will be proper we should offer a few remarks relative to its history, which, like that of most important inventions, is somewhat obscure, the origin being attributed to different ages and to different nations.

The Chinese here, as in the invention of the mariner's compass, lay a claim to a knowledge of the art long anterior to that of any European nation, and this claim is admitted by the celebrated Lord Bacon, who says, "Certain it is, that ordnance was known in the city of Oxidrates in India, and that it was this which the Macedonians called thunder, lightning, and magic; and it is well known that ordnance had been in use in China for more than two thousand years."—Bacon's *Essay on the Vicissitude of Things*.

The Greeks also seem to have had some knowledge of explosive mixtures, but not of their application, for Salomoneus was said to be able to imitate thunder and lightning, which has been supposed by many to have been performed by means of the explosion of gunpowder or some such composition; indeed it appears from various authorities, according to the statement of Dr. Watson, that a knowledge of some explosive mix-

Mechanical Processes.

Plates for enamel painters.

Transparent enamelling.

History of gunpowder.

Early claims of the Chinese.

Of the Greeks.

Manufac-
tures.

ture of the nature of gunpowder was certainly known in very ancient times both in Greece and in Asia.

It is, however, a different sort of knowledge to be possessed of the secret of making highly explosive mixtures, and that of being able to apply that substance to the purposes of war, or to the more desirable purposes of peace and the Arts. Dr. Watson very properly observes, "There are substances in nature from a combustion of which it is possible to destroy a ship, a citadel, or an army, by a shower of liquid fire spontaneously lighted in the atmosphere; every person who is aware of the dreadful fiery explosions which attend the mixture of two or three quarts of spirits of turpentine with strong acid of nitre must acknowledge the truth of this assertion; but the simple knowledge of the possibility of effecting such destruction is very different from the knowledge of its practicability, although future ages may perhaps invent as many means of making these substances unite in air, so as to make them fall down in drops of fire, as the moderns have invented of making gunpowder the sad instrument of the destruction of our species."

Roger
Bacon.

The celebrated Roger Bacon, who died in Oxford in 1292, unquestionably possessed a knowledge of the present composition of gunpowder, but there is only a very vague expression of his to lead us to suppose that he was acquainted with a practical application of it either to war or to any other purpose, although it was certainly so applied soon after his death; nor does it follow that, because he was (as is very probable) the first Englishman who was in possession of this secret, that he was also the inventor of the composition. Dr. Watson remarks that it is very probable, as Bacon was skilled in the Arabian books and sciences, that he derived his knowledge of gunpowder from the same source from which he derived much of his optical science, *viz.*, from books brought over by the Moors into Spain a few years before his own time.

State of the
knowledge
of gunpow-
der in the
XIIIth
Century.

At all events, it is pretty clear that a knowledge of what we now call gunpowder was partially possessed both in Europe, Asia, and on the coast of Africa in the XIIIth Century, but up to that time it had never been employed in war by any of those nations. Had the Art of applying it been known at the time that Mahomet and his immediate followers were extending their destructive sway by means of the most bloody warfare, there can be no doubt (supposing the knowledge to have been possessed by the Arabs) it would have been had recourse to; and if it had been so employed, there can be as little doubt that it would have been recorded by Mahomedan writers, and made the subject of miracles without number.

Not applied
to war in
Europe
prior to 1300

From these circumstances, then, we may conclude that gunpowder was not known as an auxiliary in war during any part of the XIIth Century, but there seems as little doubt that it was so employed in the XIVth Century. The battle of Cressy was fought in the year 1346, and an historian who lived at the time is quoted by Spondanus as affirming, that the English greatly increased the confusion the French had been thrown into, by discharging upon them from their cannons hot iron bullets. Neither is this the first notice of the use of guns in battle, for, three years before the battle of Cressy, the Moors were besieged by the Spaniards in the city of Algeziras; and it is stated by Marina, a Spanish historian, "that the besiegers did great harm amongst the Christians with iron bullets they shot, and this," says the author, "is the first time

Battle of
Cressy

we find any mention of gunpowder and ball in our histories." The Earls of Derby and Salisbury are mentioned by the same author to have assisted at this siege, and, as they returned to England in 1343, it is not an improbable conjecture that, having been witness of the havoc occasioned by the Moorish fire-arms, they brought the secret from Spain to England, and introduced the use of artillery into the English army in the above celebrated battle.

About the same time the use of gunpowder was introduced into the armies of Germany and Denmark, and even the invention itself has been attributed to a German monk, Barthold Schwartz, but this claim, although very generally admitted, cannot be well grounded if what is stated above is to be, as there seems no reason to doubt it may be, considered authentic.

The statement of Schwartz being the inventor is made by father Kircher, with some particulars which gives to the story an appearance of fact, and to this is probably to be attributed the general credence which it obtained. He says that this monk, who was a learned alchemist, having mixed together, with a medical view, nitre, sulphur, and charcoal, a spark accidentally fell upon the mixture, blew up the pot in which it was contained, and caused a dreadful explosion. The monk, astonished at the event, made several repetitions of the experiment, and thereby fully discovered the nature of gunpowder in the year 1354; and the same author gives an account out of some old book he had read of the use he afterwards made of his discovery, *viz.*, by means of it frightening some robbers from their haunts in certain woods in his neighbourhood. Other historians, as Sebastian, Munster, Pontanus, a Dane, and Polydore Virgil, all agree in giving the invention to Schwartz, but the facts before stated are certainly at variance with it, and if the date upon an old gun can be received in evidence, it would appear that, even before the siege of Algeziras, ordnance was known in Germany, for it is mentioned in the *Acta Eruct.* 1769, p. 19 that in the armoury of Amburg, in Bavaria, there is a piece of ordnance on which is inscribed the date 1303. This, however, may be an antedate, and cannot be admitted as any material evidence.

Father
Kircher's
account of
the inven-
tion by
Schwartz,
1354.

There is another case quoted of an earlier date for the use of gunpowder, which appears, however, to be an error. A Danish historian, quoted by Camerarius, relates that Christopher, King of the Danes, was killed in battle by the stroke of a gun in the year 1280, which, if correct, would carry the invention back to the time of Roger Bacon; but it appears that Waldemar did not succeed to the crown of Denmark till the year 1332, and that his son Christopher was killed in a naval engagement several years afterwards, probably subsequently to the siege of Algeziras and the battle of Cressy.

(718.) *Gunpowder Manufacture.*—Having given the preceding concise sketch of this important substance, we shall now proceed to describe the processes followed in its manufacture.

Gunpowder is made by the combination of three materials, saltpetre, sulphur, and charcoal, and according to the practice of the Government works in the following proportions, *viz.*

Saltpetre by weight.....	75
Charcoal ditto.....	15
Sulphur ditto.....	10
Gunpowder.....	100

Manufac-
ture of gun-
powder.

Manufac-
tures.
Method of
refining the
saltpetre.

In England the saltpetre employed in the manufacture of this article is either that imported immediately from the East Indies, or that extracted from damaged gunpowder; in either way, however, it may be said that the East Indies furnish the whole supply of saltpetre for English consumption, as we have already stated under Saltpetre Works. This article as imported is refined by solution, filtration, evaporation, and crystallization, after which it is fused, taking care not to use too much heat, that there may not be any danger of decomposing the nitre; by this means it is not only rendered more pure, but the water of crystallization is more certainly got rid of. The principal object in refining the nitre is to get it free from the earths and salt with which it is combined in its *rough* or imported state, and which, by deliquescing, would render the gunpowder liable to injury by attracting moisture, and thereby decomposing the accurate mixture of the composition.

The sulphur.

The sulphur used in the Government works is generally imported from Sicily, but sometimes English stone brimstone is made use of. In either case it is refined by melting and skimming, and the most impure by sublimation.

Charcoal.

The charcoal formerly used in this manufacture was made by charring wood in the usual manner; this is called charring in pits, but it is now made as described under the head Charcoal. (Art. 600.)

Powder-mill.

The ingredients being prepared according to these methods, and mixed in the proportions above stated, after each has been separately ground to a fine powder, the mixture is in this state sent to the mill, which consists of two stones placed vertically, and running on a bed-stone, in a way similar to those described in the mortar-mill, oil-mill, &c. The composition is spread on the bed-stone and wetted with as small a quantity of water as will, together with the revolution and weight of the runners, bring it into a compact body, but not into a paste. After the stone-runners have made the proper number of revolutions over it, and it is in a fit state, it is taken off. The powder-mill, such as we have described, is generally worked either by wind, or water, or horses, being merely covered in by a few light boards, and only about 40 or 50 pounds of composition is worked at a time, as an explosion will sometimes happen from the runners and bed-stones coming in contact, or from other causes; and when such accidents do occur they would of course be more terrible, and extend the evil further in proportion to the quantity.

Corning house.

(719.) *Corning-house.*—The composition as taken from the mills is sent to the corning-house to be corned or grained. Here it is first pressed into a hard and firm body, broken afterwards into small lumps, and the powder then grained, by these lumps being put into sieves, in each of which is a flat circular piece of *lignum vitæ*. The sieves are made of parchment-skins, having round holes punched through them. Several of these are fixed in a frame, which by proper Machinery has such a motion given to it as to make the *lignum vitæ* in each sieve go round with a certain velocity, breaking the lumps of powder and forcing them through the sieves, and thereby forming grains of several sizes; the grains are then separated from the dust by proper sieves and reels. They are then hardened, and their rougher edges taken off by running them a sufficient time in a close reel which has a circular motion given to it. The powder for guns, mortars, and small arms, is generally made at the same

time, and always of the same composition; the difference being only in the size of the grains, which are separated by sieves of different degrees of fineness.

The gunpowder, thus corned, dusted, and reeled, (the latter being denominated glazing, as it puts a slight degree of gloss on it,) is sent to the stove and dried, keeping the heat down below what would be liable to decompose the sulphur, a proper thermometer being provided for the purpose.

The drying-house is either heated by steam or by what is called a *gloom*. The latter is a species of stove formed of a large cast-iron vessel projecting into one side of the room, which is heated from the outside. From the construction it is nearly impossible that fire or sparks can be thrown from it, and the powder is not removed from the house till the heat has subsided; the gloom is, moreover, furnished with a copper or other covering; still, however, one cannot feel the same degree of security in this mode of drying as in that by steam-pipes, which are certainly in every respect to be preferred.

(720.) *Improved mode of mixing, granulating, &c.*—The preceding is a concise view of the usual process of manufacturing gunpowder as generally followed in English works, but there are some minutiae connected with the mixing, corning, &c., which differ considerably under different makers, and on the precision of which much of the quality depends. Sir William Congreve, who was Director of the Laboratory of the Royal Arsenal at Woolwich, in 1815, took out a patent for certain Machinery to be employed for these purposes; the process, as described by the author, is exceedingly ingenious, and a concise account of it cannot fail to be interesting to the reader.

Machine for mixing the ingredients.—As it is highly important for the production of good gunpowder that the constituent parts should be uniformly mixed, too much care cannot be bestowed on this process, and the Machine we are about to describe seems well suited to this purpose. It consists of three hoppers for each of the three ingredients, fixed in one frame close together and in one line, and a cylindrical hair or wire brush, about three inches in diameter, and six or eight inches long, is fitted on an axis into an oblong aperture of the same dimensions in the bottom of each hopper. On this cylindrical brush the composition in the hopper lies, so that when the brush is made to revolve on its axis the composition is drawn out in a fine stream of the same breadth as the brush; and on the same principle as cotton-thread is drawn by the revolution of the rollers in the cotton-mill: the fineness of the stream being adjusted by the closeness with which the cylindrical brush is fitted to the aperture of the hopper. With this arrangement it follows that the quantity of composition drawn out in a given time depends upon the number of revolutions made by the rollers in that time, and consequently any required proportion of the different ingredients may be drawn from each hopper, according to the different velocities with which each of the brush-rollers are made to revolve; and these being regulated according to the due proportions required for gunpowder, and their motion being sustained and ensured by proper Machinery, the means are provided of keeping up these streams for any length of time required.

Thus far we see the uniformity with which the quantities of each ingredient are delivered; we have now to

Mechanical
Processes.

Drying or
gloom.

Improved
mode of
mixing.

Manufac-
tures.

explain the method adopted for uniting them into one heap. This is effected by a broad endless band which runs on rollers beneath and in a line with the hoppers and brushes, this band being kept in motion by the same Machinery which gives motion to the brushes; and on this band, so in motion, are received the three proportionate streams of composition above described as issuing from the three hoppers. In proportion, therefore, as the velocity of this band is increased, in respect to the velocity of the issuing streams, so will these streams be reduced in thickness, drawn out by this second process, and carried away upon the band in laminæ, thinner and more attenuated than as they issue from the hoppers. It follows, therefore, as the band passes with the same velocity under each of the hoppers, that it will be covered with a stratum of composition composed of the three ingredients, uniting upon the band in the due required proportions, and attenuated by a sufficient velocity in the band, so as to bring the falling particles of each ingredient into a due and almost mathematical juxtaposition with those of the other two, and in the predetermined proportions regulated by the velocities of the extracting rollers. It is almost needless to add that the combination of particles thus collected is detached from the band where it turns over the end roller, and is there gathered into a single receiver. In this way every mill-charge may be mixed separately, or in greater quantities, according to the size of the apparatus; and although the mixture thus obtained may be considered as nearly perfect, still, as a few small lumps will sometimes escape the revolving brushes, it has been considered advisable to pass the composition from this receiver through another Machine, for the purpose of breaking down any such irregularities, and for the more complete incorporation of the ingredients. This second Machine is somewhat similar, but consists of a single hopper only, having a large cylindrical brush at the bottom of it, the lower part of which acts against a fine wire sieve, embracing half the brush.

By this means the contents of the hopper, consisting of the compound of ingredients united as above described, are forcibly driven through the sieve, and reduced to the finest powder, so as, by a few repetitions of the process, completely to remove any imperfections that may remain after the first mixture. The repetition of this operation to any desired extent, in one continued process, is effected by letting the contents of the hopper fall into the inside of a vertical drum fitted with ledges. This drum works round the hopper, so that, when revolving, it carries the composition received from the hopper at the bottom round the top, and drops it back again into the hopper from the ledges as fast as it issues; and for as long a time, or as frequent repetitions of its passage through the brush and sieve, as may be wished, by keeping the Machine at work.

Such is the plan proposed by Sir William Congreve for mixing the ingredients, and it must be admitted to be exceedingly ingenious and effective; and as one of the principal objects of the mill is the due combination of the component parts, the latter process, it is said, may be considerably shortened, and it was the opinion of the inventor that it might probably by this means be wholly dispensed with. We must, however, suppose that it passes from the last mixing Machine to the mill, and there undergoes the process already described, and thence to the press.

Press-house. (721.) *Press-house*.—The alteration made here is that,

instead of the coarse mode of throwing the mill-cake under the press as it comes from the mill, leaving considerable intervals in the mass, and forming thereby a soft and brittle cake in the parts near these intervals, the mill-cake is now broken down by passing it through brass rollers with coarse teeth, by which it is so reduced that it may be distributed very regularly, and the cake produced becomes thereby of a more uniform consistence; moreover, the cakes are thus formed much thinner than in the common way: that is to say, instead of being $2\frac{1}{2}$ or 3 inches thick, they are made here, by using a greater number of copper-plates, into cakes of only $\frac{1}{8}$ of an inch thick, and thus are more fitted for the next operation of granulating, which process is also performed by a new Machine.

(722.) *Granulating Machine*.—This consists of three parts in three distinct rooms, one principal, and two other adjoining small rooms, lightly covered in, having a strong brick wall between them to act as a traverse to each; in the principal or middle room of the three the actual granulating apparatus is placed.

In the first of the adjoining rooms is contained a large hopper, in which the pressed cake is deposited, in quantity not exceeding a barrel at a time, to supply the Machine in the second or middle room; while the third room contains a bin into which the powder passes as fast as it is granulated in the second, and is thence carried away, at stated periods, to a magazine, to prevent any accumulation in the granulating-house.

The granulating Machine, in the middle room, consists of two sets or pairs of brass rollers, about two feet six inches in length and two inches in diameter, supported in the middle, and divided into teeth, each pair working together by means of a pinion or nut at the end of each roller, so that they draw inwardly, like the rollers of a flattening-mill, or those of a cotton-mill.

The teeth of these two sets of rollers are of different degrees of fineness, and the rollers are set at different distances; the coarsest so far apart as readily to draw in the thin pressed cake above described. These pairs of rollers are set in a strong frame of cast-iron or wood, about six feet high and eight or ten feet long, more or less; so that the upper and coarser pair are at the top of the frame, about eighteen inches or two feet higher than the other pair. They are then connected either by a double crank, or by a rod and pinion, or in any other way, so that when one pair is set in motion by the principal mover of the Machine, whatever it may be, water, or horse, or any other power, the other pair will also move; and they are, moreover, so arranged, whether in a direct position over one another or obliquely placed, that whatever passes through the upper or coarser pair shall pass also through the finer or lower pair; the teeth of the coarse pair of rollers are so constructed, that the thin press-cake being brought gradually into a hopper surmounting those rollers, is immediately drawn through them, and broken into irregular fragments or heads; which fragments, again passing through the lower or finer rollers, are finally and at once reduced into perfect grains of every different size required; which are separated in one operation by falling from the lower pair of rollers upon a series of wire sieves, calculated according to the different sorts required. These sieves being of a sufficient length, from four to six feet, are placed obliquely, and kept in motion by the common mover, so that the different grains pass from top to bottom of these sieves in the act of separation, which, at the same time,

Mechanical
Processes.

Granu-
lating Ma-
chine.

Manufactures.

cleanses the powder from the dust. These different sorts of powder and their dust, having thus been separated and carried to the bottom of the sieves by their motion and obliquity, are, from each respective sieve, delivered into a flat funnel, which disposes of each sort upon a horizontal endless band of canvass, or other material, running from the foot of the granulating Machine in a flat trunk through the traverse wall into the bin above-mentioned, as being provided in one of the adjoining rooms for receiving the powder when granulated; there being as many bands and as many compartments in the bin as sorts of powder, including the dust, and these bands being kept in constant motion by the first mover, so as to carry off every grain of powder and dust as fast as it is formed, and thereby prevent any accumulation about the Machine in the act of granulation.

Method of feeding the Machine.

It remains now only to describe how the Machine is fed with cake, that also being done by a mechanical process, to prevent the necessity of any person being near when actually at work. This is, in fact, performed by nearly the same operation as that by which the powder is carried off after it is grained, that is to say, by bands of canvass, or any other suitable material, passing from the hopper in the outer room, through the traverse wall, into the hopper over the upper set of granulating rollers, in the middle room; these bands, however, are stronger, more tightly strained, and have straps of leather, or cords, or small rods sewed flat upon them every nine or ten inches, to raise the cake out of the hoppers, the back of which being placed at an angle of forty-five degrees of inclination, and the band moving up that back, the cake, although thrown *indiscriminately* into the hopper, is, nevertheless, drawn out of it in single pieces, lying flat upon the band, any surplus, not actually raised and supported by the cross straps on the band, falling or sliding back from the great inclination at which the strap moves in its progress up the back of the hopper. Having surmounted this, however, with its due load, namely, covered with a single layer of cake, the band takes a horizontal course through the traverse wall, until it reaches the edge of the hopper of the granulating Machine, and there discharges its load in regular quantities between the upper set of rollers for granulating, as already stated.

It is almost needless to say, the only remaining detail of the Machinery necessary to be described is the form of the teeth of the rollers: they are of various sorts, either grooved horizontally, so as to bring the teeth to sharp or spiral grooves, and, either cross-cut or not, into rings, leaving void spaces between them, equal in breadth to the rings of the teeth themselves, and so arranged on the reciprocal rollers, that the rings of the teeth on one roller shall work in the void spaces of the other, and *vice versa*, but no part of the rollers or teeth actually touching in any case; thus arranged the teeth never clog. Here also it must be stated that the edges of the large rollers in the press-house, for breaking down and preparing the mill-cake, are formed on similar principles to those of the granulating rollers, only coarser in proportion as the mill-cake is thicker than the press-cake.

These granulating Machines have several advantages; in the first place, the whole operation being, as above described, performed by mechanical means, requires no person to be present in either of the rooms, except at the moment of the discharging the powder from the

bin, and of replacing the cake in the hopper, which is performed at the same time during which the Machine is stopped; and, moreover, as no accumulation can take place in any part, it follows that there is no personal danger to any one, neither can any serious mischief happen to the Machine itself with the traverse walls, if the quantity of cake put in at each charge be limited, as above stated, to a barrel at a time; the small quantity which can ever exist in the principal room protects the Machine itself, while the adjoining buildings being of a slight and temporary nature, an explosion with the quantity limited would be of little consequence, no person being, as before stated, required in the building when the work is going on. The Machine above described was found competent to manufacture six barrels of gunpowder per hour.

Mechanical Processes.

(723.) *Qualities of different gunpowders.*—The preceding description of the Machine invented by Sir William Congreve is given principally from a short Treatise by the inventor, published in 1815, on the process of making gunpowder, and it must be admitted to be exceedingly ingenious and that it is attended with considerable advantages; but the inventor, perhaps, rates these too highly in some parts of his account, which, therefore, we have not noticed. With respect to the advantage of such accurate mixing there can be no reasonable doubt, but that the most accurate mixing will ever supersede the mill-work is contrary to the opinion of those who are best qualified to judge on this subject. In vol. ix. of the *Phil. Mag.* a Paper is given by Mr. Coleman, of the Waltham Abbey Powder Works, descriptive of the general process at that time followed, to which we have been indebted for several particulars in the leading part of this notice. We propose also, in conclusion, to state the results of several experiments by the same gentleman on the qualities of gunpowder as depending on different modes of mixing, proportionate strength, specific gravity, &c., most of the experiments having been from large quantities of powder made in the above Works.

Qualities of gunpowder.

Results of Experiments.

1. One hundred parts of composition gain from three to four or five parts in weight by the water used at the mill.
2. This water appears to be totally got rid of by the succeeding processes of manufacturing and stoving, and, therefore, it follows that the aqueous matter in gunpowder is only what is at first contained in the ingredients.
3. The ingredients, only pulverized and mixed, have a very explosive force.
4. Gunpowder granulated after having been but a short time in the mill has only acquired a portion of its strength.
5. It is not till it has been the proper time in the mill, and been properly made there, that it has obtained its full power.
6. The strength of gunpowder does not depend on the granulation, the dust of gunpowder, after manufacture, having nearly the same force as when granulated.
7. Powder made in every respect the same, but of two sorts of charcoal; *viz.* pit and cylinder, is very different in strength, the cylinder charcoal rendering the gunpowder made therewith much superior to that made with pit-charcoal.

Experimental deductions.

Manufac-
tures.

8. Powder undried, in every stage of manufacture, is weaker than when dried.

If the composition on a mill explodes by any accidental cause, shortly after it has been put on the stones, it goes off with a very slight explosive force, principally in flame; but if it has been an hour or two under the runners, and then explodes, it more or less destroys the mill, throwing the boards of the covering and sides to a considerable distance.

The specific gravity of gunpowder is differently stated by different authors. Count Rumford makes that of solid gunpowder 1868, and of loose but well shaken gunpowder 1077; but Mr. Coleman states that from repeated trials he found that the density of powder varies considerably from different causes in the manufacturing; for which reason, he says, no exact specific number can be assigned to it, but he has no doubt the above numbers of Rumford are the greatest it will ever attain. The author says he has frequently seen it less than that of water.

Causes of
the explo-
sive pro-
perty.

(724.) *On the cause of the explosive quality of gunpowder.*—The following deductions are founded on the preceding experimental results by Mr. Coleman, which he states as below.

1. That the explosive force of gunpowder depends very materially on the carbon employed. This he conceives to be borne out by his experimental result 7.

2. That the mixture only of the ingredients without milling does not make that necessary incorporation of the parts for proper combustion, and for the full explosive effect. Experimental results 3, 4, 5, 6 are supposed to bear out this conclusion.

3. That the less moisture there is in gunpowder, the stronger is its effects. This is clear, from gunpowder which has attracted any degree of humidity being weaker than when first made.

After the above statements and deductions Mr. Coleman observes: "I shall now beg to submit some ideas that occur to me from a consideration of the whole of the circumstances I have related, and from what may be deduced from an examination of the component parts of gunpowder. It appears to me that no part of the explosive force consists in elastic vapour, formed by the combustion, from water contained in it. So small a portion of water is in the ingredients, and I have observed that not any is gained in the manufacturing, that I cannot conceive any water is carried off undecomposed, but that it is converted into hydrogen and oxygen gases. Mr. Cruickshank observes, after the explosion of gunpowder over mercury no water is seen. I am of opinion that the explosive force of gunpowder consists wholly in the several gases formed by the combustion; and that the quicker it takes fire, the more gas is generated in a given time, and its force consequently greater. Lavoisier observes, its effect is increased by the quantity of caloric disengaged at the moment of deflagration."

It seems, therefore, that the combustion is carried on by the oxygen supplied from the nitre; that this gas is instantly taken up by the sulphur and carbon; and, converting those substances into carbonic and sulphuric acid gases, azotic gas being at the same time liberated from the nitre, the water which may be in the nitre, and also that which is in the charcoal, is decomposed; and the oxygen taken up by the carbon and sulphur, and the hydrogen set free. The force arising from these gases, with the increased elasticity they

receive from the increase of temperature caused by the combustion, is surely sufficient to account for the effects we observe in gunpowder.

Mechanical
Processes.

It may probably serve to elucidate the subject, if we consider a little minutely what the component parts of gunpowder are from chemical analysis.

Nitre.—100 parts of nitre, according to Kirwan, consist of

Potash	51.8	} dried in a heat of 70°.
Acid	44.0	
Water of composition	4.2	

By several experiments the author found that nitre, which had been dried at 70°, loses 3 per cent. in melting.

Lavoisier says, 100 parts nitre consist of

Potash 49, dry acid 51, and that this dry acid is	
Oxygen	40.6
Azote	10.4

Charcoal, according to the same Chemist, absorbs 2.5714 of oxygen in combustion. From various experiments made by Mr. Coleman he had reason to conclude, that charcoal, when used, contains about $\frac{1}{8}$ th of water which it has absorbed.

Sulphur, according to Berthollet, requires for every hundred parts 36.8 oxygen to form sulphuric acid; of course a small quantity of oxygen would be necessary for their conversion into sulphuric acid gas; taking this at 30 per cent., which is probably not far from the truth, and admitting this, the following will turn out to be the quantities of the constituent principles which enter into the composition of gunpowder.

75 parts of nitre, containing.	{ Dry nitre...	74.25
	{ Water	0.75
15 parts charcoal.	{ Carbon	13.13
	{ Water	1.87
10 parts sulphur.....	Sulphur	10.00
		100.00

And these again contain

Nitre 75 =	{ Potash .. 36.75	Char- coal {	Oxygen . 1.60
	{ Oxygen .. 30.34		Hydrogen 0.27
	{ Azote ... 7.80		Carbon . 13.13
	{ Hydrogen 0.11		
			75.00

Whence 100 parts gunpowder consist of

Potash	36.75
Carbon	13.13
Sulphur	10.00
Oxygen	31.94
Azote	7.8
Hydrogen	0.38
	100.00

We know that all the charcoal is not consumed in the act of combustion. Mr. Cruickshank states, that 3 parts remain of 100 equal parts of gunpowder, therefore 10.13 parts are destroyed. Now,

10.13 parts of carbon absorb ..	26.05	of oxygen.
10 parts of sulphur absorb	3.00	ditto.

Oxygen used	29.05
Oxygen in the ingredients	31.95

Surplus of oxygen

2.90

It is clear the smallest error in the quantity of charcoal used will easily account for this difference of oxygen.

Manufac-
tures.

On the above calculation it seems the quantity of each ingredient is pretty well regulated, and that the gases formed will be expended in producing the effects we observe in the combustion of gunpowder.

Residuum
of fired
gunpowder.

The residuum of fired gunpowder Mr. Howard thinks to be an alkaline sulphuret mixed with carbonate and sulphate of potash. But by several trials made by Mr. Coleman, he found reason to be of opinion, with Mr. Cruickshanks, that this residuum is very deliquescent, and when exposed to the air absorbs moisture sufficient to dissolve a part of the alkali; and in consequence the charcoal becomes exposed, and the whole assumes a dark or black colour, and this residuum is potash united with a small proportion of carbonic acid and sulphate of potash, a very small quantity of sulphurate of potash and unconsumed charcoal, and that 100 grains of gunpowder yield 53 grains, of which three are charcoal. *Phil. Mag.* vol. ix.

Sugar Works.

Sugar
works.

(725.) Before entering into a description of the culture and manufacture of this important article of commerce, it may not be uninteresting to the reader to trace the origin of this valuable plant, and briefly to sketch its progress from the first discovery until it has attained its present importance, not only with respect to the immense capital which it employs and the extent of public revenue which it yields, but as an article become necessary to the comforts of mankind.

For the following history of the sugar plant we are indebted to Mr. Potter, who has lately published a very valuable Work, entitled *Practical Directions for the Culture of the Sugar Cane, and for the Manufacture of its Products*. The author has collected with much labour all the facts relating to this subject, and enters into it at considerable length.

History of
sugar.

The Chinese appear to have been the first people who discovered the properties of the sugar-cane; and it is tolerably well ascertained that the inhabitants of that Country enjoyed its use some centuries before it was known and adopted in Europe. There is no mention made of it in the History of Ancient Egypt, Phœnicia, or Judea, and the Greek Physicians are the first who have spoken of it under the name of Indian salt, which, from the sweet taste and other characteristics assigned to it by Dioscorides and Pliny, without doubt was the same material which we now denominate sugar-candy.

Indian salt was brought to Greece and Rome from Arabia and India within the Ganges, but it was not cultivated or manufactured in those Countries. The cane at that time grew only in the Islands of the Indian Archipelago, in the Kingdoms of Bengal, Siam, &c., and the sugar that was produced from it passed with perfumery and spices, and other merchandise, to the Countries on this side of the Ganges. It found its way into Arabia in the XIIIth Century, the period at which merchants first began to visit India, and to traffic in the Indian articles of commerce. If the cane had been the produce of that part of Asia which lies between the Ganges and the Mediterranean Sea, or of Arabia or Africa, this plant, which grows so easily in all warm Countries, and which reproduces itself without culture, would certainly not have escaped the observation of the different Tribes who inhabited and roamed over every part of these Countries.

Marco Paulo, a noble Venetian, was the first European who visited the Countries in which the cane actually grew. He found that Bengal produced spices, ginger, and sugar in great abundance, and, upon the whole, gave so favourable an account of the Country, that the merchants who had formerly gone to Ormus, for the purpose of trafficking with the Indians, now directed their steps to Bengal itself.

Mechanical
Processes.

The precise period after the voyage of Marco Paulo at which sugar was first introduced into Egypt does not appear; we are only able to ascertain that at the end of the XIVth Century the cultivation of the sugar-cane, and the manufacture of its juice, were practised generally throughout Arabia, Egypt, and several other parts of Africa; and the testimony of various travellers, particularly that of Giovanni Leoni, proves that in the XVIth Century an extensive trade in sugar was carried on in Arabia Felix, Nubia, Egypt, Morocco, and Ethiopia.

In 1420, when the Island of Madeira was discovered by the Regent of Portugal, he introduced the sugar-cane from Sicily. It was cultivated with success there as well as in the Canaries, and soon after the sugar of these Islands, particularly Madeira, was greatly preferred to that of any other Country.

The Portuguese began the cultivation of the cane in the Island of St. Thomas (under the Line) immediately on its discovery; and we are told, on the authority of a Portuguese pilot, that in 1520 this colony had more than 60 sugar manufactories. The rich inhabitants had 200 or 300 Negroes employed in their plantations, and there were made on the Island 150,000 arobes (4,650,000 pounds) of sugar.

Soon after Columbus discovered the New World, one Pierre d'Etienne took the sugar-cane to Hispaniola, since called St. Domingo, and now Hayti. A Catalanian, named Michel Ballestro, was the first who expressed the juice from it, and Gonzales de Velosa the first who concentrated this into sugar. The latter built a mill on the river Nigua, and at his own expense sent for workmen from the Island of Palms (one of the Canaries) to manufacture the sugar. Sloane relates, on the authority of Martyr, that the cane flourished extremely well in St. Domingo, that it grew to the size of a man's wrist, and that the same root produced 20 or 30 shoots; while from those of Valance there were only 5 or 6. He says, also, that there were in 1518 28 manufactories on that Island. The cultivation of the sugar-cane in St. Domingo certainly extended with very great rapidity, and the produce was so considerable, that we are told the cost of the magnificent palaces of Madrid and Toledo, which were erected in the reign of Charles V., were entirely defrayed by the proceeds of the port duties on the sugar imported from Hispaniola.

Sugar-cane
first intro-
duced into
America.

Father Labat fixes the period of the first establishment of sugar plantations, by the Spanish and Portuguese settlers in America, at the end of the year 1580; but he must certainly, Mr. Potter remarks, be in error, since it appears that, in 1518, there were 28 plantations in St. Domingo alone.

Labat also asserts, on the authority of unknown and obscure travellers, that the sugar-cane is indigenous to America; but this appears to be without sufficient foundation, and is contradicted by the testimony of the most credible travellers. It is certainly mentioned by Captain Cook among the articles which the natives of the Pacific

Manufac-
tures.

West
Indies.

Islands brought to his ship, but we have not the slightest evidence to show that it is indigenous to the colonies of America; on the contrary, there is every presumptive evidence to disprove it.

In 1641 sugar-canes were transplanted from Brazil to Barbadoes, and thence to our other West India Islands. But the sugar made in Barbadoes was at first so bad, that it was considered scarcely worth sending to England, being full of molasses. In 1650 it had become much better in quality, but even then could not compete with that made in Brazil. Sugar was made by the English in the Island of St. Christopher in 1643; by the French at Guadaloupe in 1657. When Jamaica was taken from the Spaniards by the English, there were only three small sugar plantations on it, which were very soon much improved and increased.

Having now traced the steps by which the sugar-cane was introduced into the different parts of the New World, we shall endeavour to describe the progress which has taken place during that period in the process of the manufacture.

The Art of crystallizing sugar, as pursued by the Chinese, was in accordance with the soundest principles of Chemistry. It is thus described by Rumphius: "The expressed juice," says he, "is received into large boilers, placed over brisk fires; as the juice evaporates more is added, till it becomes red and thick; then it is put into deep earthen vessels, which are taken to a warm place. The sugar at the surface forms crystals, which are united in white clusters, called cakes of sugar, and that which crystallizes underneath is called Muscovado. The sugar is refined by being clarified in large boilers with whites of eggs; a little chicken fat is used in the operation; it is afterwards put into large earthen plates to crystallize. That which is obtained from cakes of sugar is very white and hard, resembling crystal; it is called *male sugar*: that which is obtained from Muscovado, the crystals of which are sweeter, and less hard and fine, is named *female sugar*."

Rumphius does not speak of the use of lime or other alkalis in evaporating the juice or refining the sugar: hence we may conclude that the Chinese and Indians did not use them, or this naturalist, whose accuracy is so well known, would not have omitted to mention the fact. It appears, then, certain, from the form in which sugar first came into Europe, as described by Dioscorides and Pliny, and from the state of that which Barthema and Barbossa found in the Indies, that the art of extracting the sugar, and of refining it, consisted among the Chinese in obtaining it in the greatest purity, under the regular crystalline form, such as it is in the state of sugar-candy. Rumphius says, "The Art of manufacturing the juice of the sugar-cane is not very ancient among the Indians; they either learnt it from the Chinese, or the desire of gain stimulated them to its discovery. Even now the Chinese are the only people who refine sugar in Java, and we can hardly doubt that the different Arts required in the cultivation of the plant, and the manufacture of sugar for domestic uses, were known by the Chinese from the highest antiquity."

The method employed in Arabia and Egypt to clarify the cane juice seems to be unknown; but it is very evident, by the foul and black sugar in which these Countries traded, that they followed plans quite different from those of the Chinese. The merchants who introduced the cane from India certainly neglected to bring

also the necessary instructions as to the methods of preparing the juice; and the difficulties which the Arabian cultivators experience doubtless caused them to try the use of all kinds of ingredients for its purification, and probably to invent conical vessels for crystallizing and cleansing the sugar.

The Venetians introduced sugar-refining into Europe at the end of the XVth Century. At first they imitated the Chinese, and sold the sugar which they purified in the shape of candy, clearing and refining the coarse sugar of Egypt three or four times over: they afterwards adopted the use of cones, and sold refined sugar in the loaf.

Sugar-refineries were soon established in all the commercial cities of Europe, and multiplied with wonderful rapidity, so that this article, which but a few centuries before was unknown to the people of the Continent, soon became one of the most important articles of commerce. It is unnecessary to describe the methods employed at that time for refining sugar; they were very various, and, from the want of that aid which the advancement of the Science of Chemistry has afforded to our modern refiners, were not conducted upon any fixed principle, and a great portion of the saccharine properties of the juice was wasted or destroyed during the operation.

Culture of Sugar.

(726.) The plant from which the sugar is obtained is known to Botanists by the name *Saccharum officinarum*, and is a genus of the *triandria digynia* class. Its characters are these: leaves flat, entire, smooth; panicle loose, with long, simple, slightly zigzag strokes; flowers in pairs, one of them stalked; calyx lanceolate, naked, except at the base; corolla awned. The stem, or cane, is one or two inches in diameter, with frequent joints; leaves from one to three inches broad.

Dutrone states the period of the sugar-cane arriving at full maturity to be from twelve to twenty months; but he was unacquainted with the Otaheitan variety, which was introduced into the West Indies about the end of the last and beginning of the present centuries. This is much larger and finer than the Brazil cane, and comes to maturity in about ten months in the elevated parts of the older settlements of the West India Islands; but in vales, and in the low alluvial soils of the colonies, where the land has not been much cropped, the plant is oftener from twelve to sixteen months, and even longer, in becoming fully ripe.

The cane plant is produced by the development of buds of a slip put into the earth, and this slip generally comprehends the top part, stripped of its leaves, and the two or three upper joints of the cane. Mr. Potter recommends holes to be made from fifteen to eighteen inches square, and about eight, ten, or twelve inches deep. These holes are made about two feet apart from each other in rows which are three feet distant, but this depends very much upon the soil, and the practice is not uniform throughout the Islands. The rows should be marked out by a line, and the ground divided into pieces about seventy feet broad, for the convenience of carting. The hole is banked up round its margin with the earth thrown up by the hoe, and manure is put into it. Two or more cuttings are then laid longitudinally in each hole, and at first these are covered with earth to the depth of one or two inches. The plant is thus placed in the most favourable state

Refining
sugar intro-
duced into
Europe.

Culture of
the sugar-
cane.

Manufac-
tures.

for receiving and retaining the water acquired either from rain or irrigation; the loose state of the earth allows the roots to penetrate and spread with facility, while these numerous and spreading roots supply in great abundance the moisture necessary for the vegetation of the plants.

The soil generally acknowledged to be most favourable to the growth of the cane is a mixture of clay and sand; and although the effects of the rain on this soil are apparently soon over, its surface quickly drying, the inner portion retains a considerable degree of moisture even in the driest weather, and it has the advantage of seldom requiring trenches to be made even in wet seasons. Plant-canes in this soil, Mr. Edwards states, have been known in very fine seasons to yield $2\frac{1}{2}$ tons of sugar per acre. This soil very much predominates in St. Domingo; but in Jamaica is confined to particular districts, and even to particular spots.

Black mould of great varieties is also favourable for the production of the cane: the best is found in Barbadoes, Antigua, and some other of the West India Islands; but there is a species of this mould in Jamaica little inferior to it, which abounds with limestone and flint on a sub-stratum of soapy marl. Black mould on clay is more common, but it is generally only in a very thin stratum, and the clay is tenacious, and retentive of water; this last sort of land, in consequence, requires great labour, both in ploughing and trenching, to render it profitable; but properly pulverized and manured it becomes extremely productive.

Canes will not flourish on mere sandy soil; to make them grow there requires a great expense for manure, as well as frequent rains, or the command of water for irrigation.

A proper attention to the manuring of land is of the greatest importance to the sugar-planter. Mr. Potter remarks: "When land is unproductive we should inquire into the cause of its sterility, which must necessarily result from some defect in the constitution of the soil; some lands of apparently good texture are yet extremely barren, in which cases the cause can only be ascertained by Chemical analysis. By this means the noxious principle which exists will easily be discovered, and most probably easily destroyed. If any of the salts of iron be found present, they may be decomposed by lime. If any inert vegetable matter be indicated, this may be removed by lime, paring, and burning. If there be a deficiency of vegetable matter, it may be supplied by manure; and if there be an excess of silicious sand, a mixture of marl will tend to correct it.

"In stiff heavy soils chalk and sea-shells are used with great advantage. Low swampy grounds, besides the assistance of lime, chalk, or sand, should be well drained, and every facility given for the escape of stagnant waters, and the overplus of those which collect after storms; the land should be divided by wide ditches into parallelograms, or beds, the drains being from ten to one hundred feet apart, according to the degree of moisture of the earth; and each of these beds should be raised in the middle, gradually sloping towards the ditches.

"Lime is beneficial to almost every soil, and especially where the salts of iron are found; but where carbonate of lime already exists in the soil, lime and chalk are, of course, useless, inasmuch as there is little or no undissolved vegetable matter."

The manure generally used in sugar-planting is a

compost formed, first, of coal and vegetable ashes, drawn from the fires of the boiling and still-houses; second, feculences discharged from the still-house, mixed up with the rubbish of buildings, &c. &c.; third, refuse, or field-trash, that is, the decayed leaves and stems of the canes; fourth, dung obtained from the horse and mule-stables, and from fixed and movable pens; fifth, good moulds collected from ravines, gulleys, and other waste places.

The first is supposed to be a manure in itself for cold and stiff clays, and it is the custom in some places in which this soil is found to carry ashes out in Autumn, and, when the land is holed, a quantity of about fifteen or twenty pounds is put into each hole, and mixed with the mould, at the time the plants are put into the ground.

Between August and November is generally considered the best time for planting; the young canes nourished by the rain then become sufficiently luxuriant to shade the ground before the dry weather sets in, thus keeping the roots cool, and the earth around them moist. The season for planting, however, depends so much on local peculiarities in different Countries, that no general rule can be given. Cazaud, who appears to have had much practical experience, recommends May and June as the most advantageous period for planting. After employing the first six months of the year in the business of the crop, he then plants the land from which the canes were cut in January, and only plants one-sixth part of his land every year, leaving the rest for rattoons (or the canes proceeding from the old stumps.) He cuts his whole plantation every year, and thus both his plants and rattoons are cut at eleven months' growth.

Mr. Cazaud has largely illustrated the reasons and advantages of this method, the fundamental principle of which is the necessity of planting the canes in the only season fitted to accelerate and preserve them, the weather in the Windward Islands being commonly dry from the 15th of February to the 15th of May: from that time the rain is moderate until August, increasing to November, then decreasing till February, and thus the progression of the rain keeps pace with that of the cane, when planted in May. The maturity of the cane, as regards its essential salt, he asserts does not depend upon its age, but upon the season; canes, whatever their age may be, being as ripe in February, March, and April as the nature of the soil ever allows them to be.

Another system is also advantageously followed in some situations, which consists in planting in August and September, and allowing the plants to proceed as usual until January, when the young plants are cut close to the ground with knives, and the remainder spread on the ground over the roots, which soon afterwards send forth a number of vigorous luxuriant shoots, all of equal growth. It is said that by these means the canes are not too rank in the stormy months, while they come to perfection in good time in the succeeding Spring.

On some soils it is found better to depend chiefly on ratoon canes, by which means the produce of sugar per acre, if not equal to that from fresh plants, yields, perhaps, on the long run, quite as much profit to the owner, if the relative proportion of the labour and expense attending the two methods be taken into consideration.

The general practice is to plant about one-third of the cane-lands every year, which, of course, imposes a great

Mechanical
Processes.

Manufac-
tures.

toil on the Negroes, from which they are very much relieved when the planter trusts to rattcons for his sugar, in which case, instead of the excessive labour of holing and planting anew, the roots are allowed to continue in the ground, and as they become thin and impoverished, the vacant spaces are supplied with fresh plants. Mr. Potter recommends that the earth round the roots should be loosened, and cleared from weeds; and in the older settled colonies, as soon as the ground has been refreshed by rains, that the roots should have manure placed round them, which being covered with cane-trash, to prevent its virtues being dried up by the sun, is found at the end of three or four months to be soaked into and incorporated with the mould. At this period the rattcons should again be well dressed, after which very little care is requisite until the canes are fit for cutting.

If the soil is favourable to the vegetation of canes, and the land is carefully managed, the same plantation may continue twenty years without replanting, and give good crops the whole of the time; but in the common method of planting the lands are sometimes replanted every six years, but those which are poor are only continued for two or three years.

The produce of sugar-plantations is sometimes completely destroyed by a disease termed the blast, which consists of myriads of little insects, invisible to the naked eye, which feed upon the juice of the cane, in search of which they wound, and consequently destroy, the vessels; the circulation is thus impeded, and the growth of the plant is checked in proportion to the degree of the ravage. It is said that the blast never attacks those plantations where colonies have been introduced of the little animal called the carnivorous ant, the *Formica omnivora* of Linnæus, and the *Raffles* of Jamaica. Several other species of insects are also destructive to the sugar-plant. In some of the Windward Islands a kind of grub, called the Borer, *Calandra sacchari*, in very dry weather commits depredations on the cane. This insect was found fatally destructive in Guadaloupe in the years 1785 and 1786.

The Rev. Lansdown Guilding, of the Island of St. Vincent, received from the Society of Arts, in the year 1827, the gold medal for a Memoir on the insects which infest the sugar-cane in the West Indies. He states, "that by far the most common enemy is the smaller grub of the moth; these in some of the colonies, which, from the absence of mountains, or other causes, are subject to dry seasons, have been known to blast the hopes of the year, to destroy whole acres of canes, and ruin the unfortunate planter."

The object of the planter should be to prevent the insects from depositing eggs in the plants rather than to kill those which have already begun their operations; and Mr. Guilding has found from long-continued experiments that they may be almost entirely expelled from any quarter in which canes are carefully stripped of dry and useless leaves, under which, as they become loose, the female borer deposits her eggs. It is well known that the vaginating leaves of the cane hold for a long time the water which has been collected in them during rains, from which, in dry weather, the plant may doubtless derive nourishment. In the drier Islands the planter will probably object to the only plan which seems capable of lessening the number of his foes, under the idea that he will expose the plants too much to the

merciless rays of the sun, but Mr. Guilding does not recommend that a single leaf should be taken off except those which are withered, and incapable of holding water for the refreshment of the plant.

The borers are found to be much more fatal to the plants than to the ratoon canes, which should, of course, be oftener visited by the Negroes, whose business it is to collect the trash. A single cane will sometimes nourish several of the borer-worms, which perforate every joint, when the centre becomes discoloured and sour, not only yielding nothing at the mill, but communicating a dark colour and bad quality to the syrup of the sounder plants. It in consequence becomes very necessary, when the canes are cut, that those which are in any way damaged should be sorted from the rest, and not on any account sent to the mill.

The canes should be cut as nearly as possible to the ground, which will give new vigour to the rattcons that spring from the old root, while the juice from these lower joints is the richest the cane contains. It may, perhaps, be sufficient to cut off only one joint of the cane with the top from those canes which grow on very dry soils; but otherwise two should be cut, for if they be not sufficiently watered their juice will only injure the sugar, instead of augmenting its quantity.

The canes being cut are tied into bundles for the convenience of taking them to the mill. On the mountains they are carried by mules. In some parts the bundles are rolled down steep places, or passed down wooden spouts. In the plains they are conveyed in small carts, drawn by oxen or mules, to enclosures near the mills; and in Guiana in flat-bottomed punts or boats, through navigable trenches, which intersect the plantations for the purpose.

Sugar-mills.

(727.) The mill employed to press out the juice from the sugar-cane is very simple in its construction, consisting of three rollers, of about 20 or 25 inches diameter, and from 30 to 40 inches in length. Between these rollers the canes previously cut are twice compressed by passing them through the first and second roller, and afterwards forcing them round, either by hand or by a circular piece of framework, called in Jamaica the *dumb returner*, so as to pass through the second and third,—an operation which squeezes them perfectly dry, and sometimes even reduces them to powder. The rollers were formerly constructed of wood, covered with steel or iron plates, but are now generally made of cast-iron, with flutes or grooves cast in them, which are found to work more truly, and to be less liable to get out of order.

Sugar-mills are worked by cattle, wind, or streams of water, and latterly a great number of steam-engines have been sent out to the West India plantations. In situations where a fall of water can be obtained water-mills are preferable to either cattle or windmills; for if cattle are used, an extra stock must be kept on purpose, because the regular cattle of the plantation are fully employed at this season of cutting out the canes. The operations of the mill should be carried on regularly, so that the canes are ground as fast as they are brought from the fields; otherwise there is danger of their juice fermenting. For this reason windmills are very objectionable, as no dependence can be placed on them for fulfilling their allotted task in the required time.

Mechanical
Processes.

Sugar-mills
described.

Manufac-
tures.

In many windmills levers are provided, to which mules or oxen can be harnessed to work the mill when the wind fails, the Machinery of the sails being at the same time detached; but this expedient takes off the cattle from their regular employment, which is a considerable inconvenience. A water-mill or steam-engine is free from these objections; and, if it is sufficiently powerful, the whole produce of a plantation can be pressed, and the juice obtained ready for the boiling-house, in so short a time that the juice will be quite fresh. There are some water-mills in Jamaica sufficiently powerful to grind as many canes in a week as will make thirty hogsheads of sugar.

Until a comparatively recent period the cylinders or rollers were placed in a vertical position, and in a line with each other, which arrangement is still very generally adhered to. In this description of mill the rollers are mounted in an iron frame consisting of two horizontal frames, sustained by uprights, and the openings of the frames contain the brass bearings for the pivots of the three rollers, which brasses are adjustable by means of cross keys and wedges driven through the opening, so as to force the rollers towards each other, and retain them at a regular and invariable distance. The surfaces of the rollers are fluted with grooves of a small depth, which enables them to take a firmer hold of the canes, and also facilitates the running down of the juice into a pan or cistern formed round them at the lower part, at one end of which there is a spout to carry off the juice into a pipe which leads to the boiling-house. This receptacle for the juice forms a small circular channel or gutter round the roller, and has a raised rim carried round the centre part or pivot, the edge of which is higher than the liquor in the pan, to prevent the juice flowing down into the bearing of the lower pivots. The roller is supported in a brass step or bearing beneath the frame; and in some cases friction-rollers are applied beneath; the rollers are made of cast-iron, and hollow within, the external surfaces being truly turned.

The operation of this mill is extremely simple, the canes, as before observed, are made to pass twice under the pressure. This is frequently performed by hand, by two Negroes, situated one at each side of the mill; the first, who attends and feeds the Machine, takes the canes in a handful and applies their ends between the first pair of rollers, the motion of which draws them in, and they thus receive their first pressure; the other Negro, who stands behind the mill, and is termed the returner, bends the end of the canes as they come through, and holds them in contact with the surface of the central roller, so that it will carry them round by its motion and cause them to pass between the two other rollers. The second pair of rollers are adjusted so that their surfaces are rather nearer than the first pair, because as the canes are flattened and crushed by passing the first rollers they require a greater degree of pressure the second time. In the more complete mills they employ a dumb returner, instead of having a person behind the mill to return the canes; this is a circular piece of framework or kind of screen, which is firmly attached to the frame and made to encompass the back of the central roller. It receives the canes as they come through the first time, and holds them in contact with the middle roller until the ends return between the other pair, which contrivance not only saves labour but performs its work more completely than the most attentive returner can do. The canes which have passed through the mill are

squeezed perfectly dry, and are sometimes even reduced to powder. This refuse is called *cane trash*, and is used as fuel in the boiling-house.

Within a few years a considerable improvement has been made in sugar-mills by placing the rollers in a horizontal position, and arranging them in the form of a triangle, two rollers being below and one above, so that the upper roller, to which the power is applied, touches the other two, and, in fact, rests upon them; whereby the returner is rendered unnecessary because the two lower ones are so near together that the canes pass from one to the other.

(728.) Fig. 1, plate li., is a perspective view of a horizontal sugar-mill worked by steam. A A A is strong iron framing, firmly secured to the foundation of the mill; C D E are the rollers made fluted in the same manner as those already described as employed in the vertical mills; the two lower ones, D and E, have fixed bearings in the framework, and the upper one, to which motion is conveyed by the toothed wheels, F G H I, from the steam-engine, is made so as to admit of adjustment by wedges driven into the upper part of the framework; the lower rollers are placed very near each other, so that the canes are made to pass from one to the other; but as they move in opposite directions they cannot, of course, be suffered to come in contact. The advantages of placing the rollers horizontally seem to be considerable, as they admit of the mill being fed more regularly, which is done by spreading on a board or bench (seen at K in the figure) placed in a sloping direction, leading to the space between the upper part of the first lower roller, and the lower part of the upper roller. The canes, being pushed forward upon this board, enter between the two rollers and are carried forward to the other roller, and thus subjected to a second pressure, without the aid of a returner.

In vertical mills it is not at all unusual to find the rollers wear out in one part, which is generally about ten or twelve inches from the bottom, while the rest of the surface remains perfect; whereas the regular feeding of the horizontal mill causes a more equable working, and lessens the chance of accident from jerking or straining, and for the same reason the rind of the cane is less bruised, and its pith less broken in its passage between the cylinders than when the canes are carelessly crowded through them, intersecting and overlapping each other. In consequence, the cane-juice expressed by a horizontal mill is said to be much clearer and many shades lighter than that yielded by the vertical rollers.

When the canes have passed between the rollers they are received on another inclined board, which has sufficient slope to carry the cane trash from the rollers, and deliver it in a heap on the ground, whence it is taken from time to time and conveyed to the trash-house.

A full-sized horizontal mill should have rollers about five feet long and two feet diameter; if their diameter is smaller, a greater speed must, of course, be given in order to produce an equal effect, and the canes will also be more bruised than when larger cylinders are employed. A mill of these dimensions, propelled by a ten-horse power steam-engine, is capable of grinding with ease in twelve hours canes sufficient to make three hogsheads of sugar: with ten steers such a mill has been made to yield 840 gallons of juice in an hour and a quarter.

Mechanica
Processes.

Modern ho-
rizontal
sugar-mill.
Pl. li.
Fig. 1, 2,
&c.

Manufac-
tures.Conversion
of juice into
sugar.*On the Manufacture of the Juice into Sugar.*

(729.) The juice which is expressed from the canes is an opaque fluid of a grey or dingy olive colour; it is composed of two parts, one solid and the other fluid, united more or less intimately according to circumstances. The operation of the manufacture of sugar consists in decomposing the expressed juice, so as to separate the feculencies or solid parts from the fluid, and by evaporating the water contained in the fluid syrup, a regular and crystalline union of the particles of sugar or essential salt takes place.

The feculencies contained in the cane-juice are of two kinds. The first, or coarser part, proceeds from the rind, and, together with a portion of mucilage, contains a quantity of green resinous matter; the other is an extremely fine powder, which comes from the pith, and its proportion is increased accordingly as the vessels of this substance are weaker: it also contains mucilage which is sometimes very intimately connected with it.

Heat decomposes the juice of the sugar-cane in common with all expressed juices, but its action, even when carried to the strongest degree of ebullition, rarely suffices to separate entirely the feculencies of the second sort; it often even favours their more intimate union with the fluid parts. In such cases it is necessary to have recourse to alkalis to obtain a perfect separation; this latter remedy is, however, invariably employed, notwithstanding there are circumstances under which heat alone will suffice to separate completely both kinds of feculencies.

The buildings required for the manufacture of the juice into sugar, and their particular relative situations, are, of course, dependent upon the size of the estate and its localities; it is, therefore, impossible to give any fixed rule for their dimensions, but as the situation of all the buildings is dependent on that of the mill, it is highly important to select the most eligible spot for its erection: there should be a fall from it to the boiling-house, so that the expressed juice may flow without assistance from one to the other. For the same reason a fall from the boiling-house to the still-house, and again from the latter, to allow the refuse from the stills to run off, will be very desirable, while the lower the situation of the mill, compatible with these circumstances, the better. The juice or liquor is conveyed from the receiver at the sugar-mill to the boiling-house by means of wooden gutters lined with lead, and is received there in one of the copper pans or caldrons termed clarifiers. In some cases the boiling-house is furnished with only one clarifier, but in general two or three are employed, and in some large concerns as many as four are provided, the dimensions of which are determined by the power of supplying them with liquor, as the means of quick boiling is in all cases indispensably necessary, or the cane-liquor will unavoidably become tainted before it can be exposed to the fire. Clarifiers are, in consequence, sometimes made sufficiently large to hold 1000 gallons each, but on estates which make on a medium 15 to 20 hogsheads a week (which is about an average quantity) three clarifiers, of 300 or 400 gallons each, are sufficient.

The clarifiers are made flat at bottom, and each is provided with a siphon or cock for drawing off the liquor. It is also necessary that they should be provided with a separate fire, and the chimney with which their furnaces communicate should have a damper for

regulating the draught, and diminishing or stopping at pleasure the combustion of the fuel.

Mechanical
Processes.

The stream from the receiver having filled the clarifier with fresh liquor, and the fire being lighted, the *temper*, which is commonly white lime in powder, is stirred into it. The quantity of alkali is sometimes determined by measure or weight, but is more generally regulated by the practical knowledge or discretion of the person in charge of the boiling, varying, of course, both with the quantity of the lime and of the cane-liquor. Some planters allow a pint of Bristol lime to every hundred gallons of liquor; but this proportion, Mr. Edwards is of opinion, is generally found too large. The lime is perceptible in the sugar, both to the smell and taste, and precipitates in copper pans a black insoluble calx, which scorches the bottoms of the vessels, and is not detached without difficulty. Mr. Edwards, in consequence, considers little more than half the quantity above mentioned to be a better medium proportion; and that Mr. Bousie's method of dissolving it in boiling water previous to mixing it with the cane-juice, is highly judicious, as it prevents the precipitation at the bottom of the vessel which very commonly attends the use of dry lime. An instance of the injurious effects of using too much lime is mentioned in Mr. Potter's Work on sugar, of an estate in the Island of St. Christopher, the produce of which had been uniformly inferior for upwards of fifty years, during which time it had been the practice to use 3 pounds of lime in the clarification of 300 gallons of cane-juice, which has, during the last few years, in consequence of reducing this proportion to 17 ounces of lime for the same quantity of liquor, yielded sugar improved in quality and value many shillings per cent.

After the lime is added to sugar-liquor the fire is allowed gradually to increase, during which time a scum is thrown up formed of the mucilage or gummy matter of the cane, with some of the oil, and such impurities or feculencies as the mucilage is capable of entangling. The juice must never be allowed to boil, and its temperature in this vessel should never exceed 210° of Fahrenheit. It is known to be sufficiently heated when the scum begins to rise into blisters, which break into white froth, and appear in general in about forty minutes; the fire is then damped, and, if circumstances will admit of the delay, the liquor is allowed to remain twenty or thirty minutes, or even longer, undisturbed in the clarifier, during which time there ensues a more complete rising and separation of the impurities; the liquor is then carefully drawn off, either by a siphon, which brings away a pure stream through the scum, or by means of a cock at the bottom: in either case the scum sinks down unbroken as the liquor flows out, its tenacity preventing any admixture. The advantage of clarifying the juice in this manner, instead of forcing an immediate ebullition, as was formerly practised, is very great: it saves a vast labour in the scumming, which would likewise be very imperfectly performed, as the whole body of the liquid would then circulate with great rapidity, and would carry down again the impurities which had risen to the surface. The merit of introducing into Jamaica the clarifiers at present in use, with siphons and dampers, was claimed by Mr. Samuel Sainthill, and an exclusive patent to secure his claim was granted to him in 1778 by an act of the Assembly.

The liquor is received from the clarifier into a gutter or channel, which conveys it to a vessel termed the evaporating boiler; it will now, if produced from good and

Manufactures.

untainted canes, appear almost if not perfectly transparent. The evaporating boilers, or evaporators, are generally four in number, the largest being of about the same dimensions as the clarifiers, and the smallest one, which is termed the *striking-teache*, about one-quarter of their contents.

The cane-liquor is here suffered to boil; the scum as it rises is continually taken off by large scummers, until the whole liquor grows finer and somewhat thicker. This labour is continued until, from the scumming and evaporation, the liquor is sufficiently reduced to be contained in the next or second copper, into which it is then removed by ladles. In this copper the same process of boiling and scumming are continued, and if the cane-liquor is not so clear as is wished lime-water is thrown into it; which addition is intended not merely to give more temper, but also to dilute the liquor, which sometimes thickens too fast to permit the feculencies to run together. When the liquor is again sufficiently reduced it is transferred to the third boiler, and so on to the last, or striking-teache, where the fire is more immediately applied; the scumming is continued throughout the process, and the coppers are sometimes kept constantly filled by lading the liquor from one to the other, as it is diminished by evaporation. The effect proposed by this is to prevent, or rather to mitigate the evil of burning the syrup, by keeping the whole surface of the copper in some measure protected from the overheating which would ensue in its upper portion, if left uncovered by the syrup. Some planters do not indeed extend this practice so far as the striking-teache, knowing by experience how necessary it is to remove the concentrated syrup as quickly as possible from the intense degree of heat to which it is subjected in this latter part of the boiling process.

The syrup remains in the striking-teache until, by evaporation, it is so far concentrated as to be capable of granulating in the cooler; and when the ebullition in this vessel is exceedingly violent, the syrup is kept from rising too high by beating it and breaking the bubbles with the ladle, or with a wooden spatula. The proper point of concentration having arrived, the fire is damped or drawn, and the sugar is laded into the cooler. The manner of judging of the required consistency is either by observing the granulations as the body cools on the back of the ladle, which is dipped into the teache for that purpose, or more commonly by taking a small portion from the ladle upon the thumb, then bringing the forefinger in contact with the same, and again separating them, noting the length to which a thread of syrup can be drawn before it breaks; if this extends to about half an inch long, it is judged that the sugar is fully boiled; but however much this plan may appear to be sanctioned by successful experience, it is evidently a rude and unscientific test. A better mode was suggested by Mr. Proculus Baker, in a Treatise published by him in the year 1775. He says, "Provide a small thin pane of clear crown-glass, set in a frame, on this drop one or two drops of the subject, and carry it out in the open air; observe the subject, and more particularly whether it grains freely, or whether a small edge of molasses separates at bottom." This method is used by Chemists to try evaporated solutions of all other salts; it may appear, therefore, somewhat strange it has not been adopted in the boiling-house; we believe, however, that this simple and efficacious plan, so long ago recommended, has not yet been gene-

rally adopted, and in some Colonies is, perhaps, unknown. Mechanical Processes.

The coolers, of which there are commonly six, are shallow wooden vessels about 11 inches deep, 7 feet in length, and from 5 to 6 feet wide. A cooler of this size holds a hogshead of sugar; and in these vessels the sugar as it cools runs into an irregular mass of semi-formed crystals, separating itself from the molasses. The cooling should be allowed to proceed slowly and gradually, which very much improves the grain of the sugar. From the cooler it is carried to the curing-house, where the molasses drains from it. It is of importance that the sugar should remain a sufficient length of time in the coolers before being put into hogsheads, time being absolutely necessary for the proper and perfect crystallization of the salts; and it is to be feared, Mr. Potter observes, that this operation of nature is often impeded, and much sugar is allowed to drain away in the shape of molasses, by too soon removing it into the hogsheads.

The curing-house is a large airy building provided with a capacious molasses cistern, the sides of which are sloped and lined with terras or boards; and over this cistern there is a frame of massy joint-work, without boarding, on which the empty hogsheads are ranged. In the bottom of these 8 or 10 holes are bored, through each of which the stalk of a plantain leaf is thrust 6 or 8 inches below the joints and long enough to stand upright above the top of the hogshead. Into these hogsheads the mass from the cooler is put, an operation which is termed *potting*, and the molasses drain through the spongy stalk and drop into the cistern, whence they are occasionally taken for distillation. This building should be sufficiently capacious to contain as many hogsheads of sugar thus placed as can be made on the estate during 3 or 4 weeks, in which time the sugar, although never entirely freed from molasses, will become tolerably dry and fit for shipment.

The above description of the process of manufacturing sugar will illustrate the general principle by which the reduction of the cane-juice and crystallization is effected; but in the order of the different operations, in the arrangement, and number of boilers and clarifiers, &c., considerable differences exist among the various manufacturers, some preferring the arrangement recommended by Dutrone, others the French method, but the greater number that described above.

(730.) Great improvements were certainly made by Dutrone in the Art of manufacturing sugar, and his method and arrangements of the building are still adhered to and preferred by some of the most scientific planters. In plate li., fig. 2, we have given the plan of the interior of a sugar-house as recommended by Dutrone. The vessels used for boiling are called collectively the laboratory, which generally consists of 3 or 4 boilers placed in a line; but whatever may be the disposition of the laboratory the order of the work is the same. The laboratory is placed in the sugar-house in such a manner that its two sides and the end formed by the concentrating pan should be isolated through the whole extent, in order that the attendance on them may be easy, and that the Negroes may be able to execute, with the greatest economy of time and means, every thing proper to be done for the perfection of the work. B B are the laboratories which are situated in the interior of the sugar-house; they contain each of them the four copper vessels *a b c d*, the capacities of which are from 500 to

Sugar-house described for Muscovado sugar.

Manufactures.

600 gallons. The first which receives the expressed juice is called the first clarifier, the next (*b*) the second clarifier, the third (*c*) the evaporator, the fourth (*d*) the concentrator. These vessels are placed very near to each other and have only an edge of 2 or 3 inches thickness between them. The masonry in which they are set forms the sides of the laboratory, the least thickness of which at the upper part is about 15 or 18 inches. The surface of the masonry is inclined 7 or 8 inches from the outer edge to the top of the boilers; there are between each, basins *e, e*, let into the masonry, where the scum which is taken off is put, in order that it may be carried back by channels *ff* to the first clarifier; between this vessel and the wall is a basin *g* which receives the first feculencies, whence they flow through a pipe *x* to a vessel (*h*) placed underneath to receive them.

It should be remarked that in the centre of the basins *e, e*, which are between the evaporator and the concentrator, there is an opening to a canal (*i*) which descends in the thickness of the masonry, and which is then continued horizontally to the bottom of a copper vessel (*k*) placed at the foot of the reservoirs for filtration and subsidence. A cooler (*n*) placed at the end of the concentrator forms also part of the laboratory. The filters *E E* ought to be large enough to contain all the expressed juice (diminished to the state of syrup, indicating 24° or 26° of the saccharometer) which the mill can furnish in 24 hours, and they should be made of masonry lined with lead and entirely covered with several sieves, the bottoms of which should be made with osier hurdles. There are fixed on these bottoms, for the purpose of filtration, first, a woollen, then a linen cloth, and lastly a reticulation of brass wire. Two leaden channels form a communication between the reservoirs and the laboratory; the one (*i*) conveys the evaporated syrup to the vessel (*k*) placed at the foot of each reservoir, whence it is poured upon the filters; the other, the opening of which is at the bottom of the reservoir *E*, carries back the syrup filtered and subsided to the concentrator.

When all is prepared for each operation, and the reservoirs for the expressed juice are filled with the proper quantity, it is made to flow into the first clarifier, and lime is added to it; and in order that the action of the lime may take place at the same time over all the juice, great care is taken to spread it by agitation for a minute or two with a ladle, and after having filled all the boilers with a charge thus tempered, heat is applied; the coppers, of course, receiving a degree of heat relatively to their proximity to the fire-place. The juice of the concentrator, therefore, is the first whose feculencies separate. These are removed by the scummer from each of the boilers as fast as they rise to the surface of the fluid and are poured into wooden buckets and carried to their place of destination (*h*.) Those of the first clarifier are poured into the basin, (*g*.) while the impurities of the second sort are poured into the little basins *e e*, and are carried back again to the first clarifier.

When the syrup of the concentrator indicates 22° or 24° of the saccharometer, the fire is damped, and the syrup is laded into the basin *e* which communicates with the vessel (*k*.) After having emptied the concentrator it is filled again with the entire charge of the evaporator, the heat is continued, and the contents of each copper pass successively from one to the other till they reach the evaporator, leaving the first clarifier

empty, and this is immediately supplied with a fresh accession of juice. In the mean time, as fast as the cane-liquor reaches the vessel (*k*.) it is poured upon the filters and falls into the reservoir freed from the solid matter which it contains. It is then in a fit state to be further concentrated by returning it the next day to the vessel *d*, whence it is conveyed to the coolers *H H*, in which the last operation, that of crystallization, takes place.

The sugar, the manufacture of which has been here described, is known as Muscovado or raw sugar, and is the material used by sugar-refiners in making white or loaf-sugar, which is also generally used for domestic purposes in England. There is also another description of sugar, which was formerly very much approved in Great Britain, known by the name of Lisbon sugar. It is still in very general use upon the Continent, and, from the additional process which it undergoes, is called in the West Indies Clayed sugar.

(731.) The process employed in the manufacture of this sugar does not differ from that above described, until it arrives at the coolers, when, instead of being removed to the hogsheads, a quantity is put into conical pots or pans, called by the French *formes*, which are placed with their points downwards, and have a hole at the bottom through which the molasses drain, but which is at first closed with a plug. When the sugar in these pots is cool and becomes a fixed body, which is generally in about twelve hours from the first putting in of the hot sugar, and may be known by the middle of the top falling in, the plug at the bottom is taken out and the pot placed over a large jar intended to receive the syrup or molasses which drain from it. In this state it is left until the molasses cease to drop, which will be generally in from 12 to 24 hours, when a stratum of clay is spread on the sugar and moistened with water, which, oozing imperceptibly through the pores of the clay, unites with and dilutes the molasses, consequently more of them come away than from sugar cured in the hogsheads, and the sugar, of course, becomes so much the whiter and purer. The pots remain for 20 days in this situation, after which the sugar is taken out and dried in the sun for some hours, and then taken to a large stove room, where it is kept in a pretty strong heat for three weeks. The stoves which adjoin the curing-house are built of masonry nearly 20 feet square, having the interior divided into different stages upon which the loaves are placed, and when sufficiently dried they are removed from the stoves and pulverized in wooden trays, from 12 to 15 feet long, and from 3 to 4 feet wide. The sugar thus pulverized is put into hogsheads and pressed down, that the casks may contain as much as possible, and is exported under the name of Clayed sugar.

This process, according to Sloane, was first discovered in Brazil accidentally by a hen with dirty feet going over a pot of sugar, which was found under her tread to be whiter than elsewhere. This method is almost universally adopted by the French planters, although generally disapproved by the English, who state, that the water, which dilutes and carries away the molasses, dissolves and carries away with it so much of the sugar, that the difference in quality does not pay for the difference in quantity. The loss in weight by claying is about one-third, so that a pot of 60 pounds is reduced to 40 pounds; but if the molasses which are drawn off in this practice be reboiled, they will give nearly 40 per cent. of sugar, so that the real loss is little more than one-sixth: but

Mechanical Processes.

Manufactures.

the distilling in that case will suffer for want of molasses, and, on the whole, Mr. Edwards considers that the method adopted by the English planters in shipping Muscovado sugar and distilling the molasses, is more generally profitable than the system of claying.

It is unnecessary to enter into a description of the variations from the above processes which are recommended by Dutrone and others, and practised by some planters; it will be sufficient to say, that the general principle is the same throughout, the variations above referred to consisting simply in the number or arrangement of the boilers or clarifiers.

Patents for the manufacture of sugar.

(732.) Several patents have been taken out within a few years for improvements in the manufacture of sugar, of which the following are most worthy of notice. In 1823, Mr. James Smith took out a patent for a method of heating boilers by high pressure steam, which has the advantage of not burning any material submitted to its action. It is proposed to apply this principle to the boiling of cane-liquor by means of double-bottomed vessels, the space between the two forming the steam boiler, but is not to subject the clarifiers to the action of steam, but simply to apply to them a more gentle degree of heat by means of the warm air of the flue previous to its passing into the chimney. We believe, however, this invention has not been introduced to any extent into the West Indies, which is probably owing to the danger and liability to derangement which attends the use of high-pressure steam.

A few years after another patent was taken for the use of high-pressure steam in heating boilers by Mr. William Fawcett of Liverpool. By his arrangement all the sugar pans were placed in a large boiler which was also proposed to supply the steam-engine.

This arrangement is said to have been successfully tried in Jamaica; but it appears to be subject to the same objections as those which have been urged against the employment of high-pressure steam under Smith's patent, namely, its danger from the degree of elasticity at which the steam must be used, and the great liability to derangement of the apparatus in a Country where engineers are not very numerous, and where few, if any, among them can lay claim to the skilfulness and ingenuity of the inventor. The unavoidably high cost of such an apparatus must also be a considerable drawback to its adoption.

In the year 1828 Mr. J. T. Beale and Mr. G. R. Potter obtained a patent for the invention of a new mode of communicating heat which can be advantageously applied to the manufacture of sugar from the same juice. This invention affords the means of regulating and controlling the degrees of heat with great precision, by transmitting caloric to the syrup by the intervention of certain fluid substances, which, unless they are purposely subjected to pressure in close vessels, can never be made to indicate beyond certain degrees of temperature, so that the degree of heat adapted to any particular operation being known, a fluid medium may be chosen and applied which will communicate that degree and no more.

This method seems to embrace all the advantages that can result from high-pressure steam, and at the same time the danger, complication, and liability to derangement is greatly avoided. The maximum degree of heat being by this arrangement altogether independent on accident or want of skill in the attendant, no injury from burning can possibly take place unless

through the choice of an improper fluid medium, which need never occur, as substances may be chosen capable of communicating any given temperature between the boiling point of water, and even lower, and the melting point of lead.

Mechanical Processes.

Mr. Godfrey William Kneller has lately patented an invention for improvements in evaporating fluids, which has been successfully employed in an extensive sugar-refinery in London, and seems to be applicable to the Colonies. The apparatus consists of a set of pipes which are inserted in the liquor to be concentrated, and which reach nearly to the bottom of the pan. Through these pipes the air is forced by means of bellows or any other blowing contrivance, and this air, escaping through the fluid, is said to carry off the watery vapour with much greater rapidity than where the strongest heat is applied, under the most favourable circumstances, without this operation.

Mr. Kneller's process seems to offer the means of concentrating syrup at a temperature equally low with the celebrated vacuum apparatus invented by Mr. Howard, and with a degree of simplicity which renders it attainable by the sugar-planter.

Sugar-refining

(733.) Sugar-refining is the Art of extracting the molasses and other extraneous matter from the sugar, and thereby giving to it a superior degree of whiteness and solidity. The Art of refining sugar was first introduced into Europe by the Venetians, and was practised in Venice some time before it was adopted in any other European Country. The foul and black sugar brought from Egypt, at the end of the XIIIth Century, was the first material upon which the Art of the refiner was exercised, which the Venetians in their commencing attempts converted into sugar-candy, similar to that which came from India; but they soon sought to obtain the sugar by a quicker and more profitable process, and for this end they invented the form of a cone or loaf, the use of which obtained universally and has continued to the present day.

Sugar-refining.

The Art of refining passed afterwards into every part of Europe in which sugar was an article of commerce and consumption; and, since America has been so fertile in the production of this commodity, refineries have consequently increased and extended all over Europe. The process of sugar-refining may be divided into two distinct operations: first, that of separating the earthy and solid parts; and, secondly, of expelling the molasses and fluid parts. The former process is effected in the common operation by bullock's blood and lime-water, and the latter by claying. Within a few years, however, improvements and alterations so marked have been made by Mr. Howard and others, that this method is in a great measure supplanted by the more modern improvements. We have, therefore, not entered at very great length into the description of it, and beg to refer the readers who are desirous of more particular information on the point to Mr. Potter's Work, in which it is described at great length.

(734.) The sugar is first boiled in pans with about six quarts of bullock's blood and a small quantity of lime-water, and the scum and impurities produced by the successive additions of bullock's blood is continually removed, till the sugar casts up only a clean milky froth which indicates the removal of impurities; and in order to heighten

Old process of refining.

Manufac-
tures.

the whiteness a little of the finest indigo is added. In this operation the heat of the fire is applied directly to the pan containing the sugar.

The next process is that of evaporating the pure saccharine solution. This is effected by a moderate fire, and the boiling is continued till the sugar has the proper degree of viscosity or ropiness, which is easily ascertained by what is called the proof-stick.

When the evaporation is completed, the hot sugar-liquor is removed out of the pans into coolers, and it is here gently stirred to prevent the formation of a crust; it is then granulated by an oar, the violent motion of which, continued for several minutes, destroys the viscosity of the sugar, and completes the granulation, the beauty of the sugar depending on the perfection of this process.

The next step is to fill the moulds, which are earthen vessels like inverted cones, the apex being placed undermost; the clarified concentrated sugar is then poured in by three successive pourings. In order to prevent the adhesion to the moulds and to lay the grain of the mass evenly and regularly throughout, the sugar is scraped from the sides of the cone by an instrument termed a bottoming trowel, and the fluid is allowed to rest a few minutes till it has got some firmness. The moulds are then stirred round three or four times and the first process is finished.

The moulds are placed above pots, and the stopper or rag at the bottom, or apex of the moulds, having been previously drawn out and a punch made with an awl, there will exude from this aperture a quantity of syrup or molasses, which is removed at the end of about twenty-four hours, and the pot replaced under the apexes of the moulds. A small ladle-full of wet clay is then poured on the face or base of each loaf or cone of sugar, which, after drying into a cake in five or six days, is removed and laid by for future use. On the day following the loaves are clayed a second time, and the cake when dry is removed like the first. The cakes are now drawn out of each mould and the irregularities and impurities brushed off, and when they have acquired sufficient hardness of surface, they are dried in a stove for five, six, or seven days to render them fit for sale.

The above is the process for single loaves or sugar once refined; but the double loaves, or those double refined, are made by a process in which the clarification is effected by the whites of about 200 eggs to each pan, and with fresh water instead of lime-water.

In the common method of refining sugar from 20 to 35 per cent. of molasses are found in the pots, and it is supposed that about two-thirds of this are produced by the intensity of the heat employed for concentrating the syrup. Various attempts have been made to remedy this evil, and in 1812 and 1813 the celebrated patents of the Honourable Edward Charles Howard were granted, although it was not until some time after this period that, through the unwearied exertions of Mr. Hodgson, these improvements were introduced.

Howard's
patent.

(735.) Mr. Howard's first patent related more particularly to the method of preparing and fining the sugar: the second to the manner of applying and regulating the heat. The sugar refined by this process is submitted to an operation preparatory to boiling, that is, raw sugar is mixed with such a quantity of water as to form a magma of the consistency of well-worked mortar: after being left at rest for the space of an hour or two, it is heated to a temperature of 190° to 200° Fahrenheit, (the improved manner of

applying heat will be described hereafter,) a thinner Mechanical
magma of sugar is added, and the whole is then put into Processes.
moulds, and when it becomes cold these are unstopped and the molasses suffered to drain from them. When the draining is completed, the upper portion of the mass of sugar is pared down to a uniform surface: the sugar so pared off is mixed with cold water till it acquires such a consistency as will not readily allow of its closing behind the stirrer, in which condition it is replaced on the firm even surface before prepared. As soon as the magma becomes moderately dry, a saturated solution of fine sugar in cold water is poured upon it about half an inch deep, or the magma may be taken off, rewetted, and replaced on this surface, and one or other of these operations must be repeated as often as the nature of the sugar may require. When this proves open-grained the finer the sugar of which the magma is made is ground the better, because the moisture is thereby prevented from descending too fast or unequally into the loaf.

The loaves are frequently examined, and the proper period for terminating the operation is ascertained by observing the degree of freedom with which the moisture is admitted, and by the colour of the molasses which drips from them. The temperature of the place in which this process is conducted should be about 60°, and raised to 80° or 90° after the surface of the loaf becomes dry for the last time. It is necessary to perforate the surface when it becomes so solid or hardened over as to prevent the access or escape of air into or out of the sugar, as otherwise the free percolation of the molasses would be impeded.

This primary operation being completed, the neat sugar is divided in the usual manner from that which retains the molasses, the former is then refined by pouring upon it 6 pounds of boiling water to every 5 pounds of sugar, deducting about 6 per cent. for the moisture previously contained in it. The sugar is dissolved by stirring, and the impurities are allowed to subside; the solution is then drawn off from the impurities, and, to complete its clarification, finings are now added, which are prepared by slacking well-burned lime with boiling water so as to obtain a cream of lime; to this is added an equal bulk of water, and the mixture is boiled for some minutes until the lime assumes the appearance of fine curd; the extraneous matter is then washed away, and the lime and liquor are run through a fine sieve.

The next part of the process is to dissolve about 2½ pounds of alum, for every hundred-weight of solid sugar that is to be refined, in about 16 times its weight of water, and to add to such solution about 70 or 80 grains of whitening for each pound of alum; and, after stirring up the mixture till the effervescence ceases, the suspended substances are allowed to subside and the solution is drawn off from the precipitated matter, and after this, are put into it the prepared lime curds shaken up with the water, the whole being agitated during the effusion. The quantity of curds must be such, that turmeric paper shall barely change its colour by being immersed in the mixture, and shall recover its yellow colour when dry. The finings thus duly prepared are suffered to settle to the bottom of the containing vessel, and, after draining off the supernatant liquor, the finings are placed upon blankets supported in the manner of a filter, and the moisture is drained off until the mass begins to contract and crack on the surface; and in this state the finings are fit for the clarification of the sugar last drawn off as

Manufac-
tures.

above described, such a quantity of that solution being added by degrees and with stirring, as will bring them to a uniform creaming state. This mixture is then poured into the whole quantity of the solution of sugar prepared for clarification, and agitated sufficiently to diffuse the finings equally.

The refined or clarified sugar is suffered to remain either during the night or about six hours, and the bright liquor drawn off from the finings by the usual methods. An evaporation is commenced and carried on at the temperature of about 200° , which is best effected by the heat of steam or water under the common pressure of the atmosphere, until the hot liquor shall have acquired a specific gravity of about 1.37; and in this state it is transferred to any convenient vessel and stirred frequently until it assumes the proper granular consistence to fill the moulds. The stoppers are taken out of the moulds as soon as the liquor is cold, and the syrup is allowed to run from it in the usual manner. During this operation, when the syrup has left the upper surface of the lump, it is pared down as before described, and if the sugar appear sufficiently fine for market, it is taken out of the mould and dried in the ordinary way, but, if it is not, the sugar before pared off the surface is mixed up to a magma with water as in the primary operation.

Mr. Howard, in the specification of his second patent, dated on the 20th November, 1813, recommends that the refining of sugar shall be effected by placing it, mixed with a proper proportion of finings, in a vessel having a perforated bottom, through small holes of which steam is allowed to enter, until the sugar is fully dissolved and heated to the temperature of 200° Fahrenheit's scale. He then proceeds, either by filtration or subsidence, to remove the impurities of the sugar: if by filtration, the solution is made to pass through Russia duck cloth; and in order to assist the operation, the heat should be kept as nearly as possible to the degree above mentioned: if the impurities are separated by subsidence, the solution must be further diluted until its specific gravity is not more than one-fifth that of water.

The most important part of Mr. Howard's invention consists in his availing himself of the fact, that fluids will boil at much lower temperatures when relieved from the pressure of the atmosphere, than when under the ordinary atmospheric pressure. He places the syrup in a close vessel, so formed as to allow the access of steam to its exterior surface for the purpose of heating its contents, and employs an air-pump with a condenser for steam by injection as used in steam-engines, so as to make and keep such a vacuum in the concentrating vessel as will not support more than one inch of mercury.

As the employment of vessels thus constructed, of course, renders impracticable the usual method of examining the progress of concentrating in the syrup, Mr. Howard furnished a scale of pressures by the mercurial gauge, and of corresponding temperatures whereby to regulate the process; and he likewise described an instrument, by means of which a sample of the liquor may at any time be taken without admitting air into the pan. This instrument, or proof-stick, is a tube inserted in an inclined position through the side of the pan, fitting air-tight at the juncture: the outer end of the tube is open, the inner end closed; but an aperture is made low enough to be immersed in the saccharine solution; concentric with this tube is inserted

another short tube, which is capable of being moved by rotation one-half turn, and has an aperture corresponding to that in the fixed tube. A plug is then constructed so as to lay hold of this inner tube, and to turn it, that its aperture may be made to coincide, or otherwise, with the aperture in the fixed tube. This plug has a cell or chamber, so situated, that when inserted for the purpose of examining the solution, it will be filled through the apertures in the tubes, when, the inner tube being turned round, the apertures will no longer coincide, and the plug, with the syrup it contains, may be withdrawn, without allowing the external air to communicate with the contents of the vacuum-pan.

When the sugar is sufficiently concentrated, Mr. Howard directs it to be withdrawn into a granulating vessel, whose office is similar to that performed by the usual cooler; this vessel, by means of steam applied to its external surface, is heated to a temperature of 150° to 180° Fahrenheit, and the usual stirring is given to effect granulation, raising the heat to 200° before filling the moulds. By this elegant method of concentrating saccharine solutions, all danger of over-heating is clearly avoided, and, as a consequence, the sugar presents a boldness and brilliancy of crystals, which had never been attained by any previously known method.

(736.) An important improvement in the manner of expelling molasses or syrup from sugar has lately been introduced by Mr. John Hague, of Cable Street, Well-close Square, who took a patent for his invention in 1816, and subsequently for the Colonies in 1828. The process is carried on by placing the sugar in a vessel or trough, having a perforated false bottom. Connected with the space between the two bottoms is the suction-pipe of an air-pump, by which a partial vacuum is formed beneath the sugar; the air in consequence rushes through, and carries with it through the perforations in the false bottoms all the molasses, leaving only the crystallized sugar in such a state that it may be immediately shipped without any liability to loss by drainage on board the vessel, or to any decomposition of the crystals through the injurious action of the impurities from which it has been thus freed. All the molasses and impurities which have been so separated are preserved for the still-house.

Sugar thus treated commands a price in the market greater than could be obtained for the same sugar in its original state by about 15s. per hundred-weight. This, however, is not all gain, as the molasses usually sold in the sugar would serve to increase by about 25 per cent. the quantity brought to market. It is stated that in the cleansing operation the crystals of sugar are washed and lessened; this, however, must be rather a fancied objection than a real one, as it is the beauty of the colour which the grower regards of most value, and the goodness of sugar for refining is by no means impaired by any artificial lessening of the grain. In newly-settled estates, and where from any cause the sugar proves dark in colour and reluctant to part with the molasses, Mr. Hague's apparatus cannot fail of proving decidedly advantageous. We understand that on a plantation where this invention is adopted, a steam-engine of twelve-horse power is sufficient during an ordinary day's working to furnish cane-juice for six hogsheads of sugar, and to expel the molasses from four hogsheads. We are also informed that Mr. Hague's patent is adopted by some sugar-bakers in France as

Mechanical
Processes.

Manufac-
tures.

the first step in refining raw sugar; but in such cases the molasses are not expelled so expeditiously or effectually as when the sugar is newly made. The adoption of this invention is now becoming very general throughout the Colonies, and it is likely entirely to supersede the more tedious and less effectual method of claying.

Other methods have been invented for expelling the molasses without the aid of heat. Mr. John Taylor obtained a patent for a mode of separating the molasses, and other soluble impurities, by mechanical pressure. The raw sugar must first be brought to a moist state, either with cold water or lime-water; but no exact rule can be laid down for the degree of moisture to be given, as it depends much on the quality of the sugar, but in general the proportion of water may be from one-eighth to one-tenth the weight of the sugar. They must be well mixed in any suitable vessel, and the whole then subjected to a pressure, carried to such a degree as to express all the fluid part therefrom; this will be found to contain the molasses and soluble impurities, and if the pressure be sufficient, the sugar will be rendered dry and much improved in colour and appearance.

The process has been tried with success in some establishments; the more general adoption, however, of Mr. Hague's invention will, of course, remove the necessity for this operation in Europe; and it would appear that the impurities can be more readily separated from the sugar when recently made, and before they have acted injuriously upon the crystals. It seems desirable on every account that the separation should be effected previously to its exportation.

We have now mentioned the most important improvements in that part of the refining process, which consists in extracting the soluble impurities contained in the sugar. In the remaining process, or that by which the earthy and other insoluble parts are separated from the pure saccharine matter, the inventions have been very numerous. We mention the following, which have been most adopted.

Two years after Mr. Howard's invention, *i. e.* in 1815, a patent was granted to Messrs Martineau for a new method of clarifying vegetable substances. The articles employed by the patentees for clarifying sugar were, first, animal charcoal; second, bituminous earths; third, certain argillaceous earths; and, fourth, the vegetable charcoal usually called lamp-black. The first-mentioned articles are, however, preferred in the process of refining and clarifying sugar, as they render it much whiter than when clarified by the common method; they are applied to clarifying in the following manner. The sugar-pans are filled with sugar and water, or lime-water, as in the common method; to this the above-mentioned substances are added, in proportions varying with the quality of the sugar to be refined—from two to five pounds of charcoal for every hundred-weight of sugar. Rather more than the usual proportion of eggs, blood, or other albuminous matter, is added, in order the better to coagulate with the dirt contained in the sugar; the liquor is then well agitated in the pans that the charcoal may produce a greater effect in blanching it; and after the coagulated albumen has completely risen in the form of scum, by the application of heat in the usual

way, it is either removed, as in the common process, or the whole of the liquid sugar is poured upon the filters at once. This method is found to whiten and purify the sugar, but it is said that more than the usual waste attends its employment. It is adopted in several refineries.

In 1817 a patent was granted to Mr. Daniel Wilson for certain improvements in boiling sugar. The object of this invention was to preserve the sugar from being charred through the exposure of the pans to the naked fire, from which they were wholly withdrawn, and their contents heated by an injection of boiling oil through tubes coiled in them. The oil which was heated in a separate boiler, and impelled through the tubes by the action of a forcing pump, returned again to the boiler after communicating heat to the sugar, in order to be re-heated and injected as before, thus establishing a constant circulation through the tubes.

This plan was pursued in one very considerable refinery some years back, which was burned down, and was the occasion of litigation with the Insurance Offices. Since that event we believe that none have been constructed on this principle.

In 1828, Mr. John Davis patented a method of boiling sugar at low temperatures by means of a Torricellian vacuum, which he obtained by connecting his sugar-pans with the upper part of a condenser, situated upwards of thirty-three feet above the level of the place at which the water from it was discharged; and as the pressure of the atmosphere does not sustain a column of water exceeding that elevation, the apparatus being first filled with water, which was permitted to escape at the lower extremity, a perfect vacuum would be obtained in the upper part of the apparatus, provided it were made completely air-tight.

In the same year, Mr. Cleland took a patent for improvements in sugar-refining, which wholly apply to the evaporation and concentration of the syrup. The principle of the invention consists in continually exposing a thin film of the liquid to the joint actions of heat and air. The apparatus consists of a convoluted worm of great length, into which steam is introduced; this is made to revolve horizontally on its axis, partly immersed in the liquid under evaporation, which is thereby constantly taken up by it in the thinnest possible stratum, and, being in contact with the hot surface of the metal, the aqueous portion of the matter is quickly formed into steam and carried off by the surrounding atmosphere.

Mr. Cleland's invention was used for some time in an extensive sugar-house in London, and was found to possess some advantages; but its use has been lately abandoned for the apparatus of Mr. Kneller, which has been before described under article Manufacture of Sugar, to which it is equally well adapted.

We shall conclude the present section by Tables of the quantities of sugar imported and exported, referring the reader who wishes for further information to Mr. Potter's valuable Treatise on the *Culture of the Sugar-cane*, to which we have been much indebted for several of the preceding particulars.

Mechanical
Processes.

(737.) Account of the Quantity of Sugar imported into and exported from the United Kingdom, the Quantities cleared for Consumption, the Rate of Duty, and the gross Amount of Revenue thereon; also the Amount of Drawbacks and Bounties allowed upon Quantities re-exported, the Net Produce of the Duty, and the Average Prices in each Year, commencing on the 5th January, from 1820 to 1831, both inclusive.

Quantities Imported.					Quantities Exported.			Cleared and retained for Consumption.	Duty per Cwt.	Gross Revenue.	Drawback and Bounties.	Net Revenue.		
Years.	West India.	East India and Mauritius.	Foreign.	Total.	Raw.	Refined.	Total as if raw.							
	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.	s.	£.	£.	£.	£. s. d.	
1820	3,769,458	277,228	162,990	4,209,676	400,423	646,245	1,499,039	2,901,864	27	5,446,905	1,521,518	3,025,387	1 13 3	
1821	3,906,966	269,162	197,402	4,373,530	483,203	645,436	1,580,391	3,056,882	..	5,581,568	1,503,862	4,077,706	1 10 2½	
1822	3,435,146	226,476	112,953	3,774,575	411,477	374,790	1,048,619	2,989,957	..	4,872,247	891,868	3,980,379	1 8 0¼	
1823	3,774,683	219,672	208,598	4,202,953	426,639	458,367	1,205,792	3,228,991	..	5,333,930	927,247	4,406,683	1 9 3	
1824	3,935,549	271,848	205,750	4,413,147	450,969	435,279	1,190,948	3,367,424	..	5,489,931	847,986	4,641,945	1 8 6	
1825	3,529,532	244,070	162,784	3,936,386	317,555	389,793	980,204	3,079,848	..	4,956,151	779,496	4,176,655	1 13 9	
1826	3,902,425	351,603	65,065	4,319,094	300,301	344,806	886,473	3,573,990	..	5,689,127	738,129	4,950,998	1 12 3¾	
1827	3,551,486	380,191	178,341	4,110,018	255,454	409,060	950,856	3,340,927	..	5,491,870	841,678	4,650,192	Average prices not published in 1827.	
1828	4,213,429	517,591	136,999	4,868,019	371,446	456,843	1,148,080	3,601,419	..	5,924,876	922,579	5,002,297		1 11 8½
1829	4,152,815	504,010	199,567	4,856,392	297,911	475,561	1,106,365	3,539,821	..	5,896,757	1,000,515	4,896,242		1 8 9½
1830	3,913,269	779,479	223,257	4,916,005	311,461	607,580	1,344,348	3,722,044	24	6,063,321	1,295,979	4,767,342		1 5 0¼
1831	4,103,746	754,969	507,547	5,366,262	420,720	581,836	1,409,840	3,787,391		5,778,414	1,127,825	4,650,589		1 3 8
The quantity of Foreign Sugar cleared from the warehouse to be refined and exported under the provisions of Acts 9 Geo. IV. cap 93, and 1 William IV. cap. 72, were:														
					Cwts. qrs. lbs.									
In 1828					1,543 0 21									
1829					9,085 3 22									
1830					42,119 3 2									
To 5th July, 1831					92,235 3 9									
Total					144,984 2 26									

An Account of the Quantity of Sugar imported into the United Kingdom, distinguishing Great Britain from Ireland, and specifying the Countries whence the Imports were received in the Year 1832.

Places whence Imported.	Quantities Imported into						Places whence Imported.	Quantities Imported into					
	Great Britain.		Ireland.		United Kingdom.			Great Britain.		Ireland.		United Kingdom.	
	Cwts.	qrs. lbs.	Cwts.	qrs. lbs.	Cwts.	qrs. lbs.		Cwts.	qrs. lbs.	Cwts.	qrs. lbs.	Cwts.	qrs. lbs.
British Colonies and Plantations in America.							British Possessions in the East Indies.						
Antigua	133,472	3 11	9,863	0 17	143,336	0 0	East Ind. Company's Territories, exclusive of Singapore	88,238	3 7	.	.	88,238	3 7
Barbadoes	244,024	2 15	22,440	0 12	266,464	2 27	Singapore	43,415	2 15	.	.	43,415	2 15
Dominica	58,270	0 25	.	.	58,270	0 25	Java	14,653	3 4	.	.	14,653	3 4
Grenada	188,231	1 14	.	.	188,231	1 14	Philippine Islands ..	28,924	3 25	.	.	28,924	3 25
Jamaica	1,416,187	3 16	15,501	2 2	1,431,689	1 18	Cape of Good Hope.	8,762	0 7	.	.	8,762	0 7
Montserrat	20,855	2 20	.	.	20,855	2 20		183,995	1 2	.	.	183,995	1 2
Nevis	39,843	1 19	.	.	39,843	1 19	Foreign Colonies in the West Indies.						
St. Christopher	80,602	0 20	.	.	80,602	0 20	Cuba	210,843	3 5	.	.	210,843	3 5
St. Lucia	29,648	1 19	18,317	1 23	47,965	3 14	Porto Rico	2,027	2 1	.	.	2,027	2 1
St. Vincent	186,812	1 15	.	.	186,812	1 15	St. Eustatius	1,559	0 25	.	.	1,559	0 25
Tobago	108,100	3 10	.	.	108,100	3 10		214,430	2 3	.	.	214,430	2 3
Tortola	14,999	0 24	.	.	14,999	0 24	United States of America	518	3 11	.	.	518	3 11
Trinidad	233,201	0 16	79,064	2 22	312,265	3 10	Brazil	147,315	0 5	.	.	147,315	0 5
Bermudas	0	2 0	.	.	0	2 0	Sierra Leone	1	0 18	.	.	1	0 18
Demerara	681,362	0 14	55,199	1 12	736,561	1 26	States of Rio de la Plata	3	1 19	.	.	3	1 19
Berbice	137,457	0 20	.	.	137,457	0 20	Europe	8,005	1 9	.	.	8,005	1 9
British N. American Colonies	12,118	1 7	.	.	12,118	1 7		155,843	3 6	.	.	155,843	3 6
	3,585,188	1 13	200,386	1 4	3,785,574	2 17	Total	4,666,689	0 18	201,059	1 20	4,867,748	2 10
Mauritius	527,231	0 22	673	0 16	527,904	1 10							

(738.) Table of the Quantity of Sugar exported from the United Kingdom, specifying the Countries whereto the Exports were made, and whether raw or refined, in the Year 1832.

Places whereto Exported.	Raw.					Refined.		
	Of the British Plantations.	Of Mauritius.	Of the East Indies.	Of the Foreign Plantations.	Total of Raw Sugar.	Actual Weight Exported.	The same stated as Raw Sugar in the proportion of 34 cwt. of Raw to 20 Refined.	Total stated as Raw.
	Cwts. qrs. lbs.	Cwts. qrs. lbs.	Cwts. qrs. lbs.	Cwts. qrs. lbs.	Cwts. qrs. lbs.	Cwts. qrs. lbs.	Cwts. qrs. lbs.	Cwts. qrs. lbs.
Russia	18 0 13	22 1 0	3,293 3 6	51,627 0 3	54,961 0 22	9,240 0 23	15,708 1 11	70,669 2 5
Sweden	.	.	319 1 17	16 2 2	335 3 19	28 3 7	48 3 26	384 3 17
Norway	.	.	381 0 4	623 3 26	1,005 0 2	363 0 16	617 1 11	1,622 1 13
Denmark	2 1 1	.	1,035 2 26	6,485 1 25	7,523 1 24	332 0 22	564 2 26	8,088 0 22
Prussia	.	1,446 3 9	16,794 1 8	19,327 2 13	37,568 3 2	77,420 0 4	131,614 0 7	169,182 3 9
Germany	31 1 7	1,138 2 12	9,945 3 23	39,719 2 1	50,835 1 15	177,110 0 24	301,087 1 13	351,922 3 0
The Netherlands	6 1 4	5,394 2 6	41,830 1 18	79,208 2 18	126,439 3 18	3,646 3 14	6,199 2 21	132,639 2 11
France	1 2 26	31 3 6	11 3 10	4 3 2	50 0 16	22 3 12	38 3 12	89 0 0
Portugal, Azores, & Madeira	14 1 4	24 3 16	104 1 26	551 2 9	695 0 27	413 2 7	703 0 6	1,398 1 5
Spain and the Canaries	1 0 14	9 3 8	20 0 11	.	31 0 5	499 3 22	849 3 18	880 3 23
Gibraltar	18 1 3	22 3 12	9 2 26	4 2 2	55 1 15	4,829 3 26	8,210 3 24	8,266 1 11
Italy	54 2 8	593 0 24	11,376 1 16	55,437 0 24	67,461 1 16	130,900 0 25	222,530 1 14	289,991 3 2
Malta	3 1 21	1 1 7	510 0 26	.	514 3 26	4,964 2 22	8,439 3 26	8,954 3 24
The Ionian Islands	3 3 13	42 0 2	358 1 24	157 1 23	561 3 6	6,136 1 2	10,431 2 17	10,993 1 23
Turkey & Continental Greece	9 1 13	11 2 0	2,543 1 13	745 3 13	3,310 0 11	15,803 1 7	26,865 2 15	30,175 2 26
Morea, Greek Islands	.	.	.	2 1 5	2 1 5	321 0 19	545 3 27	548 1 4
Guernsey, Jersey, Alderney, and Man	4,201 3 5	42 0 14	94 3 6	5,387 0 17	9,725 3 14	2,177 3 8	3,702 1 5	13,428 0 19
	4,366 1 20	8,781 3 4	88,630 0 8	259,299 2 15	361,077 3 19	434,211 1 8	738,159 0 27	1,099,237 0 18
Cape of Good Hope	3 2 25	38 3 3	26 2 0	3 0 22	72 0 22	214 0 23	364 0 17	436 1 11
Other parts of Africa	134 3 13	89 0 14	479 3 27	221 0 13	925 0 11	626 0 11	1,064 1 13	1,989 1 24
East Indies and China	142 2 2	440 0 13	468 0 27	307 2 20	1,358 2 6	710 2 23	1,208 0 23	2,566 3 1
New S. Wales, Swan River, and Van Diemen's Land.	109 0 8	232 2 23	300 2 27	141 1 5	783 3 7	1,461 3 24	2,485 1 10	3,269 0 17
British N. American Colonies	296 2 21	357 3 11	2,000 1 18	153 3 7	2,808 3 1	14,021 3 4	23,837 0 5	26,645 3 6
British West Indies	74 1 8	132 0 27	48 3 9	102 2 9	357 3 25	2,943 2 9	5,004 0 9	5,362 0 6
Foreign West Indies	39 1 3	7 0 8	4 0 9	24 2 4	74 3 24	163 0 10	277 1 0	352 0 24
United States of America ..	111 0 20	46 0 2	49 3 12	122 0 26	329 1 4	1,404 0 20	2,387 0 11	2,716 1 15
Mexico	11 1 7	2 0 0	3 3 16	20 1 16	37 2 11	11 1 6	19 0 24	56 3 7
Columbia	7 1 24	1 1 10	3 0 8	4 2 24	16 2 20	1 0 8	1 3 8	18 2 0
Brazil	39 0 27	4 1 12	14 0 26	40 0 15	97 3 24	.	.	97 3 24
States of the Rio de la Plata	18 2 4	2 0 26	9 2 17	24 2 22	55 0 13	.	.	55 0 13
Chili	10 1 22	.	5 3 16	19 0 15	35 1 25	4 0 2	6 3 9	42 1 6
Peru	3 3 11	11 0 21	4 1 4	5 3 16	35 0 24	6 1 26	11 0 2	46 0 26
The Whale Fisheries	.	.	.	.	.	1 0 13	1 3 17	1 3 17
Total from Great Britain ...	5,368 3 19	10,146 3 6	92,049 3 10	260,501 0 5	368,066 2 12	455,780 3 19	774,827 2 7	1,142,894 0 19
Africa	2 0 0	.	.	.	2 0 0	.	.	2 0 0
British N. American Colonies	19 2 1	.	.	.	19 2 1	.	.	19 2 1
British West Indies	.	.	.	.	.	65 2 16	111 2 10	111 2 10
United States of America ..	7 2 15	.	.	.	7 2 15	.	.	7 2 15
Total from Ireland	29 0 16	.	.	.	29 0 16	65 2 16	111 2 10	140 2 26
Total from the United Kingdom	5,398 0 7	10,146 3 6	92,049 3 10	260,501 0 5	368,095 3 0	455,846 2 7	774,939 0 17	1,143,034 3 17

*Works relating to Bleaching, Dyeing, Calico-printing, and Tanning.**Bleaching Works.*

Bleaching. (739.) *Bleaching* was formerly quite a distinct operation from dyeing, and conducted by different parties, and in distinct Works, and is still so generally when the cloth is to be left white for the market, but when the bleaching process is only preparatory to that of dyeing or printing, it is very commonly carried on in the same premises, and is, in fact, considered only as another branch of the dyer's art. We shall therefore, while we keep the process distinct from that of dyeing or printing, so far combine the three subjects as to give them in continuation, disregarding the alphabetical order of those articles which would interpose between them.

In consequence of the great advancement of the Science of Chemistry, most of the Arts depending upon it have undergone great changes, and all have been more or less improved; but there is not one, perhaps, in which the improvement has been so great, and the time of the whole operation so much expedited, as that of bleaching. The same materials, which formerly were submitted to a tedious and troublesome process for five or six months, can now be rendered as perfectly white and free from dirt in the space of a less number of days, by the use of oxy-muriatic acid or chlorine; and, in consequence of this, the old method of bleaching is now almost entirely superseded by the improved process. We shall therefore make the description of it as brief as possible, in order that greater length may be given to illustrate the modern practice.

Manufac-
tures.*Sketch of the Old System of Bleaching.*Old system
of bleach-
ing.

(740.) The first operation in the old system, as in the new, is to remove a substance termed sowens, which is a paste made of flour and water, used during the weaving for the purpose of closing down the fibres of the threads, and thus allowing them to pass more freely through the reed and harness; this consisted in steeping the goods in a vessel of lukewarm water, till a gentle fermentation took place, which usually required about twenty-four hours. The cloth was then taken out and well washed in a current, which removed a considerable quantity of the filth without the use of alkaline leys.

Boiling.

Boiling.—The goods were then boiled in a vessel containing a solution of potash, and furnished with a winch and rollers, by which the cloth could be moved about in the liquor, and by that means thoroughly impregnated with it. This was continued as long as the liquor appeared to abstract any colouring matter from the cloth, which was then taken out and well washed in water. The use of this process depends upon the properties which alkaline salts possess of uniting with the oily and resinous matters which are either attached to, or are a constituent part of, the vegetable fibres.

Bucking.

Bucking.—The next operation is termed bucking, and is similar in principle to the last, although a more powerful application of it. The goods are placed in a vessel termed the bucking-tub, and a powerful solution of the alkaline ley is poured upon them from a vessel where a quantity is kept constantly boiling. When the goods are thoroughly impregnated with the boiling ley, it is allowed to pass off into an iron vessel, whence it is pumped back again to the boiler, and then returned hot again upon the cloth, which process is continued for some time. The cloth is then taken out, well washed from impurities, and laid upon the ground to be whitened by exposure to the atmosphere.

Souring

Souring.—In order to dissolve and remove any metallic or earthy matter inherent in the cloth, or which may have been derived from the impurity of the alkaline solutions, an operation termed *souring* is employed: the goods are immersed for about the space of twelve hours in a mixture of sulphuric acid and water well incorporated, the proper strength of which should be about the acidity of lemon juice, and was usually determined by the taste. The goods may be put into this acid either in a wet or dry state; but the best plan is to immerse them in the evening in the acid liquor cold, to let them remain covered with it all night, then in the morning to make a fire and bring the liquor to a blood heat, in which state the goods should have a few turns, in order that every part of them may be equally exposed to the fluid. The goods are then wrapped round the winch to strain them a little, to prevent an unnecessary waste of acid, and afterwards carried to a wash-wheel or river, to be washed till there is no acid perceptible to the tongue remaining in the cloth. It is a remarkable circumstance that cloth may remain immersed a considerable time in strong acid liquor without rotting, but that, if exposed to the air or the heat of a stove, if a very small portion of the acid remains in the cloth, it becomes so concentrated by heat as to damage the material immediately, too much attention cannot, therefore, be paid to this point.

The operation of bucking was repeated for some cloths a great many times, each time requiring, with the subsequent operation of leying and watering in the

bleach field, the period of a week. The first two buckings were with very strong ley, which it was necessary to diminish in strength to prevent injury to the cloth.

Mechanical
Processes.

These operations could be carried on only during the Summer months, and during four months in the year bleaching by the old system was entirely suspended, and the capital of the manufacturers, or proprietors of the goods, locked up and useless; the immense time which the goods were under operation was also the means of a great consumption of capital. Cotton goods, which required from four to six applications of alkaline leys, consumed as many weeks in bleaching, while linens, which could not be bleached in less than from twelve to twenty applications, could scarcely be brought into a marketable state in less than six months.

Discovery of the new Principle.

(741.) Such was the state of this Art when Scheele first discovered the gas, for some time designated by the term oxymuriatic gas, but which has since been more properly named chlorine. It is generally considered that Berthollet had the honour of first suggesting the application of this material to the purposes of bleaching, and that he did, in fact, make the application in a small way in 1786. (*Ann. de Chim.* vol. ii. p. 160.) Others, however, seem to dispute this point, stating that the idea of its application belonged also to Scheele; that the latter Philosopher wrote to Kirwan, informing him of his discovery, and its application; that Kirwan mentioned the subject to Mr. Taylor, then Secretary to the Society of Arts, altogether independently of Berthollet; and that a whole piece of calico, in the state received from the loom, was, in the Spring of 1788, actually bleached, printed in permanent colours, and produced in the market at Manchester for sale, having undergone all these processes in less than forty-eight hours. This is very probable, but it does not appear to prove any thing with respect to the first suggestion of the application of the oxymuriatic acid to the bleaching process, nor is it, we conceive, of great consequence. There is no doubt that Scheele discovered the gas and its properties, and there is as little doubt that Berthollet contributed greatly to the progress which was afterwards made of the discovery to bleaching in the large way; but both seem to have been erroneous as to the theory of its action.

Scheele's
discovery.

Scheele explained the bleaching power of the oxymuriatic gas, by supposing that it destroyed colour by combining with the phlogiston, while Berthollet considered it as acting by supplying oxygen, whereas it was afterwards found that, although this new gas had received the denomination of oxymuriatic gas, it could not be shown to contain oxygen, and it could not contain muriatic acid, consequently, explanations resting on these false hypotheses were necessarily defective.

Amongst those who had the advantage of witnessing Berthollet's experiments was the celebrated Watt, who himself afterwards made some experiments, and succeeded in whitening five hundred pieces of cloth. He did not, however, pursue the subject any further, probably in consequence of his other important occupations.

About the same time a gentleman, named Cooper, formed an establishment for the purpose of applying Berthollet's discovery, and Dr. Henry of Manchester, not only engaged in a similar undertaking, but gave to

Manufac-
tures.

some of the principal bleachers the first instructions which they received respecting the new process. Dr. Henry recommended two methods of applying this principle. One consisted in immersing the goods in a watery solution of the gas, or in an alkaline ley impregnated with it, the other in exposing the goods, previously moistened with water, to the gas itself. He afterwards made an improvement by substituting lime for alkali, as a means of condensing the new gas. An air-tight chamber was prepared, on the floor of which rested a stratum of lime and water mixed together to the consistency of cream; through this chamber the goods were passed by means of a winch, and the chamber being filled with gas, the goods were alternately exposed to the lime liquor and to the acid vapour. By this means an oxymuriate, or, as we should now say, a chlorate of lime, was formed upon the cloth, which, after a sufficient continuance of the operation, was taken out and exposed to the usual process of washing, &c.

A very essential improvement in the application of lime was afterwards made by Mr. Tennant of Darnley near Glasgow, which was secured to him by a patent in 1798. It consisted of a combination of the chlorine with lime in a separate vessel, containing lime suspended in water by mechanical agitation. The redundant lime was allowed to subside, and the clear liquor, a solution of chlorate of lime, obtained, which was applied to the purposes of bleaching. This patent was afterwards set aside by the decision of a Court of Law.

Modern System of Bleaching.

(742.) The great distinction between the old and modern system of bleaching consists principally in the substitution of immersion in chlorine, for the effect formerly produced in the bleaching ground by the atmospheric air; the primary processes being the same in both, in the modern processes may therefore be thus classed, viz. steeping, bucking, boiling, immersion, souring, and washing.

On steep-
ing.

Steeping.—After the linens are properly sorted, they are washed for some hours, in order to free them from any loose matter which may be attached to them: they are then put into a large circular vat made of fir deal boards, technically termed a *kieve*, one above the other, without being too much compressed. After the goods are disposed in the kieve, it is filled with alkaline ley at a blood-heat, generally some which has been employed in bucking or boiling former goods. A piece of wood in the form of a cross is then fixed above the cloths in order to keep them below the liquid. In a few hours an internal motion is observable and an increase of temperature takes place, the liquid swells, bubbles of air rise to the surface, and a thick scum is thrown up. This fermentation continues from twelve to eighteen hours, according to the state of the weather, and as soon as it is observed to have ceased, the goods must be instantly withdrawn from the kieve and again washed, in order to be cleared from the loose filth. If they are kept too long in the steep, they are liable to considerable damage, as, after the acetous fermentation ceases, a putrid fermentation commences, and the coloured matter, instead of being loosened from the goods, is attached to them, and at the same time a dissolution of the vegetable fibre takes place, and, were they to remain too long in this state, they would be totally destroyed.

Boiling and bucking.—Boiling is now very commonly omitted, and if not, only used when the goods are nearly white; the process which follows the steeping being that of bucking, in which considerable improvements have been made. In the old method, the goods having been placed in a wooden vat, the hot alkaline ley from a boiler was admitted upon them, and, after having remained some time, it was let off by a cock at the bottom, to be returned to the boiler to be fresh heated and again admitted hot upon the goods in the kieve. It is found, however, that the admission of the liquor when hot upon the goods has a tendency to fix the colour more strongly upon them, in place of extracting it; for this reason the latter are placed in the cold liquor, which is gradually heated, and by that means the colouring matter is more effectually removed than can be accomplished by the old method. When the alkaline ley is saturated with the colouring matter, it is run off, and, instead of the former plan of carrying the goods instantly to the dash-wheel while hot, whereby a certain portion of the colour is fixed into them, the most scientific bleachers, after the ley is let off, run warm water upon the cloth, which combines with and carries off part of the remaining impurities; a stream of water is then allowed to run upon the cloth in the kieve until it comes off almost transparent. The linens may now be taken to the wash-wheel to be further cleaned without any danger of setting the particles of colour.

Immersion.—Thus far the processes described do not materially differ from the old system; we now arrive at the point where the great change takes place. The goods, instead of being laid in the grass fields for several days, are immersed in water impregnated with chlorine, chlorate of potash, or chlorate of lime, for the period of six or nine hours, after which they are washed and again submitted to the bucking process; they are afterwards again immersed in the chlorine solution, and these last operations are repeated alternately for several times, the number depending upon the nature of the materials to be bleached.

Souring.—The goods after being properly washed have now to be soured, which operation differs so little from that already described as employed in the old method, that little requires to be said on this point. The sour is prepared in a large fir tub lined with lead; as much sulphuric acid is added to the water as will give it the acidity of strong vinegar. The acid and water must be well mixed together before immersing the linens, which are generally steeped in it for twelve hours, and then dried and washed in pure water. Linen yarns and cloth are passed three or four times through the acidulous water, making it progressively weaker each time, but it is sufficient for cotton goods to be passed once. Great pains must be taken to wash the cloths perfectly before and after immersion in the acidulous water, otherwise a fine white can never be attained. It is no less important to prevent the yarns or cloth impregnated with acidulous water from remaining long exposed to the air, for, as the water evaporates, the acid becomes concentrated and the fibre is destroyed.

The souring process very commonly completes the bleaching. Some of our most eminent bleachers, however, commit the goods to the sour much earlier, which, they say, considerably hastens the removal of the colouring matter.

It is very essential that the goods should be now well

Mechanical
Processes.
Boiling and
bucking.

Immersion.

Souring.

Manufac-
tures.

soaped to correct the rigidity which is given to the fibres by the ley. Dr Ure recommends that, upon coming out of the acid bath, instead of washing them as in Berthollet's process, they should be plunged while still wet with the acid liquor into hot soap-water. The soap is decomposed by the acid, the resulting muriate of soda is carried off by successive washings, and the oil of the soap, being absorbed by the fibres, gives them pliancy and softness.

Blueing.

When a perfect white is attained, a blue tint is given in the following manner. A quantity of the oxide of cobalt reduced to a subtile powder is diffused through a little clean water. Some of the water thus charged is drawn off and passed through a silk search into a small tub filled with the most limpid water, and when the workman judges by a trial made on a handful of thread that the water is sufficiently charged, he passes through it all the threads or goods in succession, taking care to add blue from time to time to make the shade uniform. The yarn is now carried to the wringing frame, and then dried in the open air.

The preparation is the same for piece goods, for gauzes, and linens, but in some cottons a little starch is added to the water containing the azure blue. Cambrics are usually passed twice through the blue, letting them dry between each operation.

General
view.

(743.) The following number and arrangement of the processes is given in Dr. Ure's edition of Berthollet's *Treatise on Dyeing*. A solution of potash must be made in the proportion of 40 measures of water, each weighing 16 pounds, to a quintal of potash, and 1250 pounds of thread.

The linen or hempen yarns, having been steeped in water for three days, and well washed, must be submitted to the

First ley.—20 measures of solution of potash, three hours boiling. The ley on cooling being as thick as a jelly.

Second ley.—For completing the removal of as many of the colouring particles as possible. This ley contains 10 measures of solution, and the boiling lasts for two hours.

Washing.—To carry off the ley and the colouring particles which it has dissolved.

First immersion.—Liquor at 2°; that is, of such strength that one measure of liquor dissolves two measures of solution of indigo. The immersion is continued till the yarn no longer weakens the liquid, after it is restored to its standard strength.

Washing.

Third ley.—12 measures of solution, three hours of ebullition.

Second immersion.—Liquor of the same strength as the first.

Fourth ley.—8 measures of solution, two hours of ebullition.

Third immersion.

Washing.

Fifth ley.—5½ measures of solution, two hours of ebullition.

Fourth immersion.—The liquor is brought down to 1°.

Washing.—At this period the white is usually manifest.

Acidulated water.

Washing.

Sixth ley.—5½ measures, two hours of ebullition.

Exposure on the green for six days.

Washing.

Fifth immersion.

Washing.

Acidulous water.

Washing.

Seventh ley.—4½ or 5 measures, one hour of ebullition at least.

Sixth immersion.

Washing.

Acidulous water.

Washing.

Ley and soap.—3 measures of solution. To this 8 pounds of black soap are added; and the solution is heated until the hand cannot be borne in it. When the soap has penetrated thoroughly, the process is stopped

Exposure on the grass, three days.

Blueing.

After this operation, the bleaching is finished, the thread is wrung out, and is set to dry.

The operations are the same for linen cloth, only they must be preceded by the ungumming. And for cotton in hanks the same order of processes is also proper. The exact number of the operations is of course not determinate, they must be continued if the goods are not sufficiently whitened, and depend greatly upon the judgment of the person who superintends.

(744.) *Bleaching for calico-printing.*—In calico-printing, a perfect white is not required, it being necessary only to remove the colouring matter and vegetable oils. It is generally first rinsed and then steeped in warm water for a day or two, and afterwards well washed and boiled in potash ley five different times.

Bleaching
for calico-
printing.

For 2000 pounds original weight of cloth, 1000 gallons of water, and from 40 to 45 pounds of potash are employed each time. The boiling is continued 8 or 10 hours. Between each operation the cloth must be well washed, and, after the third and fourth boiling, it must be spread upon the grass, or steeped for a night or two in a weak solution of chloride of lime. After this it is immersed for a few minutes in warm dilute sulphuric acid, and then is well washed, and dried.

The common process for bleaching cotton cloth, when fixed colours are previously dyed in the yarn, is first to wash the starch and dressing out in cold water, then to boil the goods gently in soap, and, after again washing, to immerse them in a solution of the chloride of potash. These processes are repeated several times until the white is good, when they are soured in dilute sulphuric acid.

Pullicates, or gingham, which have been woven with yarn previously bleached, are first freed by washing from the starch or dressing, then slightly boiled in soap, rinsed in pure spring water, and soured.

(745.) *Bleaching muslins.*—In bleaching the coarser kinds of muslin, termed jaconot muslin, they are, after the process of steeping, boiled in a weak solution of pot and pearl ashes; after being again washed, they are twice boiled in soap alone, and then soured in very dilute sulphuric acid. They are then again washed, boiled in soap, and immersed in the chloride of potash. The boiling in soap and steeping in the chloride of potash are repeated until the muslin is a pure white, when they are soured, and washed in pure spring water.

Bleaching
muslins.

The finer fabrics of muslin, such as those kinds called mull and book-muslin, are bleached in the same manner as the jaconot, except that, on account of the fineness of

Manufactures.

Silk bleaching.

the fabric, no pearl ashes are used in the boiling, but soap only.

(746.) *Bleaching silk.*—This kind of bleaching is generally performed in the dye-house, and is thus described by Mr. Packer, in his *Dyer's Guide*. "The silk is divided into hanks, each hank being tied with a piece of string; several of these are tied together (a handful of them) by putting a piece of string through each separate skein, and tying the piece of string in a long tie, to slip easily when they are wanted to be untied.

"A liquor is prepared of thirty pounds of **WHITE** soap (dissolved in water) to a hundred pounds of silk; the soap is cut into small pieces and boiled in water; when it is dissolved, the fire is damped.

"While the liquor is preparing the skeins of silk are put on rods; as soon as the soap-liquor becomes a little below boiling heat, (for it should not boil, as boiling would tangle the silk,) the silk is to be put into it in an oblong copper, being nearly full; it is to remain in the liquor till its gummy matter has left it, which will be seen by its whiteness and flexibility. It is then turned end for end on the rods, that the part above the liquor may undergo the same operation. As soon as this is accomplished, the silk is taken out of the copper, the hanks which were first turned being soonest done.

"The hanks are now to be taken from the rods to the peg, disentangled, and nine or ten of them put on one cord, this cord passing through the string that ties each hank. When the whole is corded, it is put into pockets of coarse strong white linen, fifteen inches wide and five feet long, closed at each end and on one side; when the silk is put in, the pocket is sewed all along the other side with packthread, and fastened with a knot; four pockets will hold the whole hundred pounds.

"The pockets being thus ready, another liquor is prepared like the first. When ready, and the boiling checked with cold water, the pockets are put in and boiled well for a quarter of an hour, checking with cold water in order to prevent its boiling over; it is necessary also to turn the bags about often with a pole, or rather let two persons have a pole each for this purpose. This operation is called boiling."

In addition to the processes of boiling with soap, as above directed, Mr. N. Kirwan recommends that the silk should be winched through a copper of water at the heat of 160°, having two pounds of soda (barilla) dissolved in it; then winch or wash in water, and wring and dry. In boiling silk intended to be dyed with common colours, 20 pounds of soap will do for 100 pounds of silk; but when the silk is ungummed, it should boil for three hours and a half, water being added to supply the evaporation. Silks intended for the greatest degree of white, either to remain white, or for delicate colours, are boiled twice in soap and water, and those that are intended for ordinary colours are boiled but once, and with a smaller quantity of soap, because the little remaining redness is by no means prejudicial to many colours. Different qualities of soap are, however, necessary for different colours. When the silks are boiled they are taken out of the copper and placed in a long shallow trough, that the water may run away from them. They are then examined, and such as have yellow or lemon-coloured spots remaining are boiled again for some time until the spots are removed. The silk has now to be whitened, the process for which is different according to the white which is intended to be given it, of which

there are five kinds, termed *China white*, *India white*, *thread or milk white*, *silver white*, and *azure white*. A copper is prepared with 30 parts of water in which half a pound of soap is dissolved, and to prepare *China white*, a little prepared annatto is added, and for the remaining whites, azure in different quantities. The silk, being put on rods, is now put into the copper, and kept turning end for end without intermission until the thread is uniform. The silk whitened for some purposes is sulphured; it gives it a rustling which for some things is esteemed; but silks intended to be dyed must not be sulphured. The sulphuring is done in the following manner. The hanks are hung upon poles in an appropriate room, provided with openings for the dissipation of the sulphuric fumes when the workmen are required to enter, but must admit of being perfectly closed, so as to admit no escape of the sulphur when the goods are placed in it. The brimstone coarsely powdered is placed in an earthen pipkin, with a little lighted charcoal at bottom, under the hanks of silk, and the room is closed all night. Two pounds of roll brimstone will sulphur a hundred weight of silk.

Silks for lace, gauze, &c., are neither boiled nor ungummed, those which are naturally whitish being used for such articles. It is sufficient to dip the silks in warm water and wring them; then sulphur and azure them. They must afterwards be again wrung and sulphured a second time. The Nankin silk requires no whitening.

Description of Apparatus, with Remarks on Leys and Immersions.

(747.) Having in the preceding section given the reader a general idea of the modern processes of bleaching, we shall now enter into a few particulars, which could not be very well introduced in the general description without interrupting the connexion of the several steps which it was thought desirable to preserve; for the same reason we have not yet alluded to the apparatus which are employed to facilitate the different processes.

Bucking, which as we have seen is the first important process, is now generally in England performed by the apparatus represented in plate lii. fig. 1, which was invented by Mr. John Lowrie, and is admirably calculated for conducting this operation on the large scale; at the same time it effects a considerable saving in the quantity of alkali employed.

A is the boiler, which is filled with the alkaline ley, and B B is a kieve situated above it, in which the goods to be operated upon are placed. This kieve has an upright C C situated in the centre of it, which is furnished at the upper part with a circular metal plate D D. E E is a pump connected at the lower end with the boiler A, and has a projecting tube or spout from it, which terminates exactly over the upright C C. The operation will now be readily understood; the boiler being filled with cold ley, the pump is set to work by the Machinery, a constant stream is flowing through the projecting tube upon the plate D D, which spreads it equally over the cloth. The ley, after it has soaked through all the cloths, is admitted by a valve F again into the boiler, to be again returned by the pump on the upper surface of the cloths. Immediately the pump is set to work, a fire is put to the boiler, by which the ley becomes gradually more heated every time it passes through the cloths, which is found, as before stated, to

Mechanical Processes.

Bucking apparatus. Pl. lii. Fig. 1

Manufactures.

be more effectual in removing the colour than when admitted hot upon them. When the ley begins to boil, the pump is disengaged from the Machinery, as the ley, being completely confined in the close boiler, finds its way up the tube without any assistance.

This apparatus unites the advantage of leying in much less time at a boiling heat, and with less consumption of fuel; for, instead of having to heat a ley incessantly cooled by the transfer, and which occupies the capacity of both the kieve and the boiler, the latter alone is filled, while the heat is preserved during the running, by the agency of the vapour.

Preparation of Leys.

Preparation of leys.

(748.) The preparation of leys is a department of bleaching which requires particular attention, and the defective manner in which it is sometimes executed is the most frequent cause of the weakening of the substances subjected to bleaching. It is necessary to know the exact quantity in each ley so as to be able to graduate its respective force, and to proportion it to the quantity and nature of the materials to be bleached. As the wood-ashes, soda, and even different species of potash, all contain a mixture of earths, salts, and alkalis, their weights are a bad criterion of their quality, nor is the areometer a surer test, since the salts mixed with the alkali also act upon it.

Home, who was aware of the necessity of estimating exactly the strength of leys, attempted to determine the quantity of alkali contained in the different substances employed by bleachers, by saturating them with an acid, but the means of analysis then known did not enable him to do it with any precision. The following is the process employed by Welter, the principle of which, like that of Home, is saturation with an acid. To render the different trials comparative, the acid must be of a degree of concentration which is uniform and easily ascertained; sulphuric acid, diluted with water till it is brought to a determined point of concentration, answers very well, and this degree of concentration may be fixed by saturating a certain weight of the acid with a fixed weight of fine, pure chalk dried at the heat of boiling water. If these analyses were made on pieces of potash taken at random from the barrels, only ambiguous results would be obtained, because in the same barrel there are often different qualities; it is therefore advisable that the experiment should be made only on solutions prepared on the large scale as leys, and always with the same weights of alkali to the same number of measures of water. The most expeditious way of making this solution cold is to suspend the potash at the surface of the water in an iron vessel pierced with a great number of holes, or formed of coarse iron wire. They should not be drawn off till it is certain that the whole of the potash is dissolved, and till by agitation the liquid is rendered uniform.

To make the experiments, it is necessary to be provided with a goblet, a glass rod, a small glass measure, and a tube, having as many times the capacity of the small measure as there are to be measures of water employed to one quintal of potash. These little apparatus are represented in fig. 2, 3, 4 of the plate lii.

The tube must first be filled with a solution of potash, and transferred into the goblet; it must be then filled with the test acid, which is also poured into the goblet, the mixture agitated with the glass rod, and a

trace drawn by it on a slip of paper stained with litmus. If the trace do not become red, another measure of the test acid must be added to the goblet, and, after the mixture is well stirred, a second trace should be made by the side of the former. If the paper is not then affected, the operation must be repeated by adding other measures of the acid until a red trace is at last produced.

In comparing the qualities of several potashes, it is obvious that is the best which has required the greatest number of measures of acid to produce a red streak, since it is the one which saturates most acid. The relative qualities of the different species of potash may thus be expressed numerically, by the number of measures of acid which each of them has saturated, which in fact amounts to counting the number of traces made on the paper, taking the first for as many as the tube contains of little measures, and adding unity for each of the following marks but the last, which should not be reckoned, because its colour indicates that it is beyond the term of saturation.

To obtain suitable variations of the leys, it is convenient to have solutions of potash of uniform strength, one, for example, with which an equal number of measures of test acid and solution of potash are required to produce saturation; but, whatever be the value of the potash, its solution may be brought to this point by adding to it for every quintal of alkali as many measures of water as there were measures of acid required to effect saturation on the quantity primarily employed. Hence the number of measures of water forming the solution ought always to be equal to that which expresses the standard of potash.

If in an assay it should happen that the first trace was red, it would be necessary to add measures of the solution instead of measures of acid, and, hence, potash should be added to the solution to bring it to the fixed degree of concentration.

Another method, recommended by Dr. Higgins, for ascertaining the purity of potash, is to take a given quantity of the alkali, and dissolve it in twice its weight of boiling water, stirring the mixture during the solution of the salt; while yet warm, it must be filtered through unsized paper. When all the liquor has passed through the paper, a very small quantity of cold water is gradually poured on the saline residuum on the filter, in order to wash out the remainder of the alkali. The undissolved salt remaining in the filter is sulphate of potash, which must be carefully taken off, dried, and weighed, in order to ascertain its quantity. To determine whether any common salt is contained in the alkali which has been filtered, evaporate the clear solution a little in a sand-bath, and set it in a cool place for twenty-four hours, at the end of which time any common salt it may contain will be found crystallized in the form of regular cubes at the bottom of the vessel. The sulphate of potash and common salt, being dried, weighed, and deducted from the weight of the crude alkali employed, will give the precise weight of the pure alkali it contains.

It is considered advantageous by some Chemists to render the alkali caustic; it has been proved (*Ann. de Chem.* tom. vi.) that in this state alkalis dissolve a fourth more of the colouring matter than when they are carbonated; the most general practice is, however, to use the ley in a mild state, from an idea that the time employed injures the stuffs. Berthollet remarks that this effect must be ascribed solely to the increased energy

Mechanical Processes.

Plate lii.
Fig. 2, 3, 4.
Methods of
ascertain-
ing the
purity of
potash.

Use of
caustic
alkali.

Manufac-
tures.

acquired by the alkali, the consequences of which may be prevented by a diminution of quantity.

To render the ley caustic, lime newly slacked is put into a large tub; the solution of potash is poured over it; the mixture is well stirred together, and after settling the clear liquid must be drawn off by means of a siphon. The residuum is then to be washed two or three times, and the washing added to the ley. One part of lime is sufficient to render two parts of potash caustic; these proportions ought, however, to vary with the qualities of the potash, and it is proper to ascertain that the proportion of lime is not too great, because the property which this substance possesses of precipitating the colouring matter held in solution by the alkalis may render an excess of it injurious. On this account, some solution of potash is to be mixed with the liquor floating over the lime in the tub in which the potash is made caustic. If it become turbid it contains lime in solution, and solution of potash must therefore be added till it no longer yields a precipitate.

According to the experiments of Kirwan, *Ann. de Chimie*, tom. vi., the use of alkaline sulphurets might be tried. They have, indeed, the inconvenience of producing spots in places which come in contact with metals; but these will disappear by employing in the last leys an alkali free from the sulphurets, or by passing them at the end of this bleaching through acidulated water. The following is the order in which this celebrated Chemist has classed, according to their energy, the substances possessing the faculty of dissolving the colouring matter of flax:

1. Alkaline sulphurets.
2. Caustic potash.
3. Caustic soda.
4. Carbonate of potash.
5. Carbonate of soda.

Kirwan appears to have considered that lime water dissolves but very little of the colouring matter, which he ascribes to the small solubility of lime; but, independently of this cause, it is not probable that lime, which forms an insoluble combination with colouring matter held in solution by potash, could of itself dissolve it. He observes, that sulphur does not augment the solvent faculty of lime; Dr. Higgins has, however, stated that there is a remarkable economy in employing sulphuret of lime in bleaching, and, as proposed by him, it was extensively employed for one or two years by the linen-bleachers of Ireland. The goods, Dr. Ure remarks, were much injured by this article, but whether from its injudicious use, or otherwise, does not appear. This compound, he further remarks, however, has been recently tried in some establishments with advantage. We conclude these remarks on this process of bleaching by a Table giving the quantity of alkali in the following substances:

	Real alkali in 100 parts.	
Best American pearl ashes	60 to	73
Caustic American potashes in reddish lumps.	60	63
Second American in grey lumps	50	55
Second American pearl ashes	50	55
White Russian pearl ashes	52	58
White Dantzic ditto	45	52
Alicant barilla	20	23
Inferior kinds of barilla	10	15
Natron	20	30
Salt of tartar of the shops	0	72

Immersion in Chlorine.

(749.) This forms, as we have seen, the great distinction between the old and new process; but although every one admits the advantages of the latter, yet some difference of opinion exists as to the best way of applying it. Some Chemists recommend combining the chlorine with potash, some with lime, while others seem to prefer using it without either; but, before offering any remarks on these subjects, it will, perhaps, be well to describe the apparatus employed in each case. In plate lii. fig. 5, 6, are sections of a very complete Machine employed by Berthollet, which, with little variation, may be adapted to the preparation of any of the substances employed. The same letters apply to both figures: A is a furnace containing an iron vessel F, in which is placed the matrass containing the mixture from which the gas is produced; B is the second part of the apparatus, termed the receiver, which is made of strong oaken staves hooped with iron and covered with cement. Between the matrass and the receiver is a bottle H, in which water is placed. It has three tubes inserted into it, of which one G forms the communication with the matrass, the second K conducts the gas into the receiver, and the third S, which is open at both ends, is for the purpose of admitting air when a partial vacuum is formed by the vessels becoming cool, and is termed the tube of safety. It must be carried higher above the water in the bottle than any part of the conductor tube, otherwise the water, when pressed upon by the gas, would escape at its upper part. The portion of this tube which dips into the water of the bottle should be shorter than that of the conductor tube, which is above the level of the water in the receiver, so that when the vessels become cool, and a partial vacuum formed, the external air may enter by the tube of safety before the water of the receiver can rush in through the conductor tube.

The interior of the receiver is furnished with three inverted tubes L L L, to receive the gas extricated from the matrass, which are secured by transverse bars fixed to the circumference of the receiver; any fastenings of iron would not answer the purpose, as they would be attacked by the chlorine. The spaces between the tubes and sides of the receiver are closed, with the exception of openings which permit the liquor to pass from one tub to another, and which are placed alternately on opposite sides, as may be seen in the figure. P P P are tubes which permit the gas to pass from one tub to the one above it, when the strata of it exceeds in thickness the length which the tubes project beneath the superior tub. The tube of the upper shallow tub is made of considerable length, as shown in the figure, in order to disperse the gas, which being undissolved in the water would be diffused in the air, and annoy the workmen.

I is the immersion tub in which the goods are placed after the bucking process; it receives the liquor by a siphon R, which is placed in a tube T, leading to the bottom of the vessel B, in order that the most concentrated acid may be conducted into the immersion tub.

It is useful to attach to the upper tub a pipe with a bent extremity, dipping into a vessel filled with a solution of potash, so that in the event of the gas filling the cavity of the tub, the excess escapes by this pipe and is absorbed by the potash, thus protecting the manufactory from the inconvenience that would result from its diffusion.

Mechanical
Processes

Apparatus
used for
immersion

Plate lii.
Fig. 5, 6.

Manufactures.

The operation of the apparatus is as follows. After mixing the ingredients in their proper proportion, they are introduced into the matrass, which is then placed in the sand-bath, the sulphuric acid, previously diluted and cooled, is poured into it, and the tube of communication fitted to the orifice of the matrass. The ascent of the water of the intermediate bottle, in the tube of safety, will denote if the joints are air-tight; but this may be further ascertained by presenting to them the moistened stopper of an ammonia bottle, which will cause any portion of chlorine gas which escapes to become manifest by a white vapour. The fire may be kindled in the furnace before placing the matrass in the sand-bath, taking care that the heat is not so great as to endanger the matrass being cracked when set into it. The whole apparatus, however, may be arranged before lighting the fire; the heat is then to be very cautiously raised, till the intermediate bottle ceases to be filled with yellow vapours, and the conductor-pipe begins to grow warm, when the fire must be extinguished. Some attention must, at the same time, be paid to the receiver, the inverted tubs must be so adjusted as to be covered with water, (except the upper one,) and care must be taken to extract all the air, which may be done by a siphon introduced into the side opening.

Proportion of ingredients.

(750.) The proportions of the ingredients to be employed for the generation of the gas is a subject upon which considerable difference of opinion exists. The most important ingredient is oxide of manganese, which generally contains about 44 parts of the metal to 66 of oxygen, but as taken from the mines is generally found combined with other substances. The principal defect arises from its being combined with chalk or oxides of iron, which, when mixed with it in considerable quantities, very much weaken the bleaching property of the liquor. Before the proper proportions of the ingredients can be known it is necessary to analyze the manganese. The presence of the carbonate of lime may be known by pouring on the manganese nitric acid diluted with eight or nine parts of water; and if the manganese be good no effervescence will ensue, nor will the acid dissolve any thing, but if carbonate of lime be present it will be taken up by the acid. If to the solution a sufficient quantity of carbonate of potash be added to precipitate the lime, its weight will show how much chalk the manganese under examination contains. When oxide of iron is mixed with the manganese it is less easily discovered, but, if the iron be in such a state of oxidation as to be soluble in muriatic acid, the following process may discover it: Dissolve a portion of the manganese in strong muriatic acid with the assistance of heat, dilute the solution largely with rain-water, and add a solution of crystallized carbonate of potash. The manganese will remain suspended by the excess of carbonic acid, but the iron will be precipitated in the state of coloured oxide.

When the properties of the oxymuriatic acid, or chlorine, were first discovered, the first attempts at its application were very naturally made without combining it with any other substance. It was, however, found, in consequence of its slight affinity to the water, that so much vapour was given out, that the health of the workmen was much injured. This led to various attempts at combining it with other substances; and, soon after the practice of the new bleaching had begun to be established, a liquor, about which considerable mystery existed, was prepared at Seville, known under the name

VOL. VII.

of the lixivium of Seville, which was a combination of oxygenated muriatic acid with a certain proportion of fixed alkali. This liquor can be imitated by employing the following proportions for the distillation of the alkaline solution: muriate of soda 77 grammes, sulphuric acid 61 gr., oxide of manganese 30 gr.; the gas disengaged from these materials is received in a litre of water, in which 120 gr. of common potash or soda have been dissolved. This liquor is to be diluted for use with 10 or 12 parts of water. To diminish the offensive smell of the oxygenated muriatic acid, Des-croizilles mixed with it carbonate of lime or chalk.

Mechanical Processes.

These proportions do not materially differ from those very commonly employed at present. In Glasgow, which is the chief seat of bleaching and dyeing in Great Britain, the common proportions are equal parts of salt, manganese, sulphuric acid, and water; and in Ireland they are said to be nearly the same. Berthollet recommends 10 parts of oxide of manganese, 20 parts of sulphuric acid, and 27 muriate of soda; and Mr. Rupp, of Manchester, 3 parts manganese, common salt 8, sulphuric acid 6, water 12. These proportions, however, so much depend upon the quality of the substances employed that it is impossible to give any precise rule for them.

In the year 1798, Mr. Charles Tennant, by a well-conducted series of experiments, showed that oxymuriatic acid might be combined with the alkaline earths; lime being most readily procured, he employed that substance, and found that, by Mechanical agitation, it readily united with oxymuriatic gas, and became thereby dissolved, forming a pure and transparent solution of oxymuriate of lime, possessing the same power of retaining the gas as belongs to the alkalis.

Mr. Tennant has since carried his improvement to a greater degree of perfection by combining the oxymuriate with the quick lime in a dry state, and thus rendering it portable to any distance at a small expense. For use, the concrete oxymuriate of lime is diffused in water by agitation, and the insoluble matter contained in the lime is allowed to subside until the liquor is transparent. When drawn off for use it is further diluted with water before the goods are immersed in it.

Berthollet, in his excellent Work upon dyeing, enters into a comparison of the relative value of these different preparations, and of the nature of their Chemical action on the oxygenated muriatic acid.

The action of the water, he remarks, being very feeble, there may be obtained from it its whole sensible effect, retarded and modified at will according to the concentration which is given it. The alkalis exercise a much more powerful action on it than water does, and thereby can give a much greater condensation, repressing almost entirely its smell.

The advantages presented by the oxygenated muriate of potash, or soda, are, first, to require a less complex apparatus, for it is sufficient to employ a receiver containing the alkaline solution, in order to condense the oxymuriatic gas, with the single precaution of plunging the conductor-tube to the bottom of the receiver, and receiving the gas under a tub; secondly, to repress almost entirely the suffocating odour of the gas; thirdly, to furnish the agent of oxygenation much more condensed under the same volume, and, consequently, to render it of easier and less expensive carriage; and, lastly, to produce its effect somewhat more speedily. It has, however, these disadvantages: when a fixed

3 x

Manufac-
tures.

alkali acts on oxymuriatic acid, a portion of the acid is merely condensed, which retains the proportion of its elements, and the properties dependent on the tendency which they preserve to enter into other combinations. Another portion is decomposed, and the result of the two new combinations, which are established in its stead, gives from 5 to 6 parts of muriate of potash for 1 of super-oxygenated muriate of potash, a salt which contains nearly 0.38 of its weight of oxygen. Now the oxygen present in the last combination is so fixed down that it can no longer attack the colouring particles, nor resume the elastic state by the action of light. The whole of the oxymuriatic acid which suffers this transmutation of combination is, therefore, lost for bleaching.

We thus perceive that the oxymuriates of potash and soda ought not to produce, in their agency on the colouring particles, so much effect as a simple aqueous solution, which contains, under the same liquid volume, a quantity of oxymuriatic gas equal to what has been condensed by the alkali.

Berthollet's
remarks on
the use of
lime.

(751.) The use of lime is evidently advantageous on point of economy, and its state of condensation and desiccation renders its carriage less expensive. But it has the inconvenience of transforming a portion of the oxymuriatic acid, and of containing the super-oxygenated muriate, which cannot be indicated in this combination by nomenclature, being precise only with regard to very uniform combinations; it appears even that the proportion of super-oxygenated muriate is considerable; for if, after expelling by a slight degree of heat the oxygenated muriatic acid, which had retained its properties, the remaining substance be examined, it is found no longer to produce discoloration; and if it be urged with a stronger heat in this state much oxygen gas is disengaged. Welter tells us that in his comparative experiments he had observed that the gas condensed by lime produced only one-tenth of the effect which may be obtained when it is received in water. The use of the oxygenated lime must, therefore, the author remarks, be disadvantageous; but it may be convenient for certain purposes, from the facility of carriage and preservation, where the economy of the process is of secondary importance. Under this point of view it merits the commendation which it has received.

On the pro-
cess of
washing.

(752.) We conclude this Notice by a few remarks on the process of washing, and on the Machinery usually employed for it. Whoever projects an establishment should examine if the place where he proposes to erect it unites the advantages of fabrication, commerce, and carriage; but above all he must have good water at command, for without this condition he will not succeed in obtaining a pure white. Muddy water, which leaves a blackish deposit, may, however, be employed with success, but water whose deposit is yellow always gives an unfavourable shade. These observations are particularly applicable to the bleaching of cotton, the white of which should have the greatest purity.

Immediately after each operation it is necessary, by careful washing, to discharge from yarns and stuffs the liquor with which they are impregnated: because, if it were carried into that of the next operation, it would neutralize a portion of it, and thus impair its action. This precaution, moreover, adds much to the perfection of the white.

To wash linen or cotton yarns, a workman takes a hank in each hand, plunges them in the water, agitates, withdraws, and replunges them for three or four times, seizing

the hank each time by a different part; he then puts the two hanks together, wrings, and throws them down.

Mec hanical
Processes.

(753.) The washing of piece goods is sometimes done by hand, with the aid of a rod or mallet, but it is more commonly effected by Machinery. The Machines usually employed in this country for the purpose are termed *wash-stocks* and *dash-wheels*.

Washing-
Machine.

The wash-stocks consist of large wooden mallets which are suspended upon pivots, and can be raised by wipers on a revolving shaft through a considerable arc. The cloth is laid in a piece of wood curved hollow, termed the *turnhead*, into which the mallets, when disengaged from the wipers, fall with considerable force. The turnhead and end of the mallets are made of such a shape that the cloth is turned partly round at each blow, at the same time an abundant stream of water rushes upon the cloth, through holes in the upper part of the turnhead. This mode of washing is, however, almost entirely given up in Lancashire, where a preference is given to the dash-wheels; but in Ireland and Scotland they are still much used. In the former Country they are very commonly made with double feet, suspended above and below two turnheads, and put in motion with cranks instead of wipers. Wash-stocks, properly constructed, make from 24 to 30 strokes per minute.

Wash-
stocks.

(754.) The dash-wheel is of more recent invention, and may be considered a very important improvement upon the ordinary modes of washing. A representation of one of these Machines is given in fig. 7, 8, of the plate Bleaching: A A A is a large wheel made of wood and secured with iron hoops. It is divided inside into four compartments, (as shown by the dotted lines in the figure,) which are closed up, with the exception of apertures B B, to admit and discharge the water employed in the cleansing and openings on the opposite side, where the cloth is introduced into the wheel. These are shown dotted in the figure at C C, &c. P P is the pipe by which water is supplied to the wheel; the nozzle of the pipe is directed so as to be exactly opposite the circular aperture in the wheel, and the water being under a pressure is forced into it, during every part of the revolution, and escapes by little openings left in the circumference. Motion is conveyed to the dash-wheel by the levelled wheel D D, situated on the shaft of the water-wheel or steam-engine, which engages a similar one on the shaft of the dash-wheel. The velocity of dash-wheels requires to be nicely regulated; when it is too slow the pieces of goods merely slide down the inclined planes of the partitions, and if too rapid they are held stationary at the circumference by the excess of the centrifugal force. Twenty-five revolutions per minute is considered the proper speed for a wheel of six feet diameter; some persons, however, suppose them to perform better with twenty-six or twenty-eight revolutions. Any considerable deviation from this velocity, however, impairs the utility of the Machine, or destroys its functions altogether.

Dash-
wheels.

Fig. 7, 8

(755.) After the cloth is washed by the dash-wheel the water is generally compressed from it by means of squeezers, which consist of a pair of wooden rollers, fixed in a cast-iron framing, the lower one of which receives motion from the mill. The upper one can be moved up and down in the frame by means of a lever, so that when the end of the cloth is introduced between the rollers, and the upper one pressed down upon the lower, it receives motion from it and draws the cloth in them, by which a great quantity of water is, of course, squeezed out.

Squeezers.

Manufac-
tures.

Various other methods of washing are made use of in different factories. On the Continent a method employed is very commonly as follows: two wooden rollers placed one above the other on frames are set in the direction of the breadth of a river, the upper one of which is fluted. The surface of the under roller is smooth, and carries a handle on the axle of one of its pivots. When goods are washed by this means, they must be thrown into the river, and the ends passed between the two cylinders. On turning the winch the cloth is drawn in between the rollers, and, being pressed down by the upper one, receives a small stroke every time a groove passes. Pieces passed in this way five or six times successively are very well washed.

A variety of other methods of performing the operation of washing might be described, which we do not, however, conceive it necessary to enter into, as they generally resemble in principle some one of the processes above noticed.

*Dyeing.*History of
dyeing.

(756.) The first attempts at impressing artificially colours upon objects to which they do not naturally belong were made at so early a period, that to expect to trace them to their original source must be wholly hopeless. That the Art owes its origin to the natural passions of Man for variety and finery there can be no doubt. The Savage, as well as the man born in the midst of civilization, is equally attracted by the splendour of coloured objects, and even in the former state attempts would be made to employ some of the ready means which Nature has placed within our reach to give colour to our apparel or utensils. As Society advanced in civilization, new methods would be invented and new materials called to our aid, till the Art of dyeing assumed, at length, that degree of importance which it now possesses, and by the practice of which thousands of human beings derive their daily bread; while many others have accumulated large and even princely fortunes.

That the first efforts of the uncultivated Savage would be rude and imperfect there can be little doubt; the colours he had been at considerable labour to obtain would perhaps be fleeting and perishable, while others would be permanent; this would naturally lead to renewed efforts and to new ideas, and although many of his first trials, made without the guide of fixed principle, might be, and naturally would be, failures, others might succeed, and thus gradually lead to the Art of dyeing.

Hindus' Art
of dyeing.

The Egyptians are amongst the earliest nations of whose skill in dyeing we have any authentic account, but it is extremely probable that they derived the Art from the Hindus, and the other inhabitants of India, who state, that they practised it from a very remote period: indeed, most of the ancient Arts and Sciences seem to have arisen in that quarter of the globe, and, although, on account of the political and religious institutions of these Countries, they never attained there any great degree of perfection, they gradually spread from this source amongst other nations less fettered by prejudice, and more disposed to adopt whatever might be regarded as real improvements. The natural fertility of India, and the great variety of materials which it affords for cultivating the Art of dyeing, were extremely favourable to its early progress; but religious prejudices and the unalterable castes of Society, as above observed, imposed restraints which interfered greatly with the

attainment of perfection. It appears, indeed, that the Art of dyeing cotton was in the same state when Alexander invaded the Country as it is even at this day, their processes being still so complicated, tedious, and imperfect, that they would be impracticable in any other Country, in consequence of the cost of labour they incur; in fact, European industry has far surpassed them in correctness of design, variety of shade, and facility of execution: and, if we are inferior in the liveliness of some few of the colours, it is solely to be ascribed to the superior quality of some of their dyes, or perhaps to the length and multiplicity of their operations.

Mechanical
Processes.

The Egyptians do not seem to have made any important additions to the knowledge of dyeing, which they borrowed from their Eastern neighbours, and indeed little could be expected from the genius and industry of a People who were strictly prohibited by the principles of their Religion from changing even the most indifferent customs. It appears, however, from Pliny, that they were acquainted with a mode of dyeing very much resembling calico-printing. He mentions that the Egyptians began by painting on white cloths with certain drugs, which in themselves possessed no colour, but had the property of abstracting or absorbing colouring matters; that these cloths were afterwards immersed in a heated dyeing liquor of a uniform colour, and yet, when removed from it soon after, they were found to be stained with indelible colours, differing from one another according to the nature of the drugs which had been previously applied to the different parts of the stuff.

Art of
dyeing
in Egypt.

The most celebrated colour among the Ancients, and that which appears to have been brought to the greatest perfection, was the purple. It was to chance alone, according to the traditions of antiquity, that they owed this discovery. A shepherd's dog, instigated by hunger, having broken a shell on the sea-shore, his mouth became stained with a colour which excited the admiration of all who saw it, and which was afterwards applied to stuffs with success; but there is some discordance in the details of ancient writers of the circumstances of this event. Some place the discovery in the reign of Phœnix, second King of Tyre, 500 years before Christ: others at the time that Minos the First reigned in Crete, about 1439 years before the Christian era. But the greatest number agree in giving the honour of the invention of dyeing purple to the Tyrian Hercules, who gave his first trials to the King of Phœnicia. The King was so jealous of the beauty of this new colour, that he forbade the use of it to all his subjects, reserving it for the garments of Royalty alone. Some authors, however, relate the story differently: Hercules' dog having stained his mouth with a shell which he had broken on the sea-shore, Tyras, a nymph of whom Hercules was enamoured, was so charmed with the beauty of the colour, that she declared to her lover that she would see him no more till he brought her a suit dyed the same. Hercules thought of a way to satisfy his mistress; he collected a great number of shells, and succeeded in staining a robe of the colour the nymph had demanded.

Purple of
the
Ancients.

Such are the different traditions handed down by the Ancients of the origin of the purple dye. They are evidently blended with fiction, yet they may serve to fix the epoch of this discovery. Whether this Tyrian purple was similar to that mentioned in Holy Writ, as used by Moses for the vestments of the High Priest and the ornaments of the Tabernacle, may admit of some dispute, since it is not certain, according to M. Huet, that the

Manufac-
tures.

word *argaman* of the Hebrew text, which all the interpreters translate by *purpura*, means in reality that colour.

This colour was so highly valued by the Ancients, that it was either consecrated to the worship of the Deity, or conceived to be fit only for the garments of Royalty. The Babylonians devoted this purple to the dress of the idols, and most of the other nations of antiquity seem to have done the same thing. Pliny informs us that it was used by Romulus and the succeeding Kings of Rome, as well as by the Consuls and first magistrates under the Republic. The Roman Emperors at last appropriated it entirely to their own use, and denounced the punishment of death against those who should dare to wear it, though covered with another colour.

This absurd and tyrannical restriction confined the dyeing of the Tyrian purple to a few individuals, and in a short time the knowledge of the process was entirely lost. In the XIIth Century neither the shell-fish which furnished the dye, nor the methods which the Ancients employed to communicate to cloths the rich and purple hue which it afforded, were at all known, and, on the revival of Learning, it was even suspected by many that the accounts which have come down to us respecting this celebrated colour were entirely fabulous. Notwithstanding the very high esteem in which the Tyrian purple was held by the Ancients, and the great encomiums which have been bestowed upon it by many of the Moderns, the loss of it is perhaps scarcely an object of regret. The shell-fish which furnishes this dye probably exists now in as great abundance as formerly. It has been so accurately described that it may be recognised, and it is in fact stated that shell-fish have been found near Nicoya, a small Spanish town in South America, which possess all the properties described by Pliny and other ancient writers. These shell-fish, it appears, are at present used in dyeing cotton on the coasts of Guayaquil and Guatemala. Cole in the year 1686 discovered some of them on the English coast, and Plumier found a species at the Antilles. Reaumur has made many experiments on the whelks which he obtained from the coasts of Poitou, and Duhamel has minutely examined the colouring matter of the purple shell-fish, which he found in great abundance on the coast of Provence. He observed, that this liquor does not take a purple colour without the action of light,—a circumstance which Reaumur had before remarked respecting that of the whelks: that, although at first white, it becomes of a yellowish-green, which deepens to a sort of blue; that it afterwards reddens, and in less than five minutes becomes of a very fine deep purple. In all respects the colour produced possessed the character of the ancient purple. If this method, therefore, of dyeing purple is no longer practised, it is not on account of our ignorance of the process, but because we are acquainted with more beautiful, as well as much less expensive, dyes; though, as Dr. Bancroft remarks, the purple afforded by the shell-fish in question may still be applied with advantage in topical dyeing, for which but little colouring matter is required.

Dyeing
amongst the
Greeks and
Romans.

The Art of dyeing seems to have made but little progress among the Greeks,—a fact which must undoubtedly be ascribed to the little estimation in which the Arts that contribute to conveniency or luxury alone were held by that warlike and high-minded People.

The Art of dyeing linen appears to have been unknown in Greece before Alexander the Great invaded

India, where, according to Pliny, his captains in skirmishing on the banks of the Indus first saw, to their astonishment, the enemy changing the ensigns of their vessels, and suddenly displaying others of different colours. Even the dyeing of woollen stuffs seems to have made but little progress at that time, as the same author, after declaiming against the luxury of his contemporaries for wearing cloth dyed of colours which rivalled those of the finest natural flowers, observes, that none of these flowery colours were in use during the time of Alexander. It is probable, however, that the companions of that conqueror brought back from Persia and India some information respecting the rich dyes employed in those Countries, which they afterwards diffused among their Countrymen.

Mechanical
Processes.

It appears to have been from the Greeks that the Romans derived all their knowledge of dyeing; they imbibed in some measure from them the same feeling of contempt with regard to the Art, so that not much progress was made during their time. They appear, however, to have set a very high value upon a red colour, from an insect termed *kermes*, or *Coccus ilicis*. Pliny mentions that this colour was sometimes employed by them, with the colour of *murex* and *baccinum*, (the shell-fish which gave the Tyrian purple,) in producing a sort of purplish-crimson called by the Romans *hyssginum*.

The first discovery and application of the colouring property of this insect in the Art of dyeing does not seem to be known. A species of the insect is mentioned by most of the ancient Hebrew, Greek, Latin, and Arabian writers, but we see nothing of its application to dyeing. Pliny states that *kermes* was procured from both Asia and Africa, from Attica, Galatia, Cilicia, and also from Lusitania and Sardinia, but those produced in the last-mentioned place were of the least value. Pausanias says they were to be found in Phocis. As the *coccus* is likewise mentioned by Moses and other Hebrew writers, *kermes* must have been also met with at that period in some of the remote Countries of the East.

It is uncertain whether the Romans understood the use of alum as a mordant. Pliny describes several species of alum, of which the island of Cyprus afforded two, one white and the other black; the white alum, he adds, is principally used for dyeing wool with clear and bright colours; the black for dyeing brown and dark colours. Beckmann supposes that the alum of the Ancients was very different from the triple compound to which the Moderns apply the term alum, which seems to be very probable.

Use of
alum by the
Ancients.

The Romans appear to have had various other colours besides the two principal ones above mentioned. It was customary among them from the earliest times for newly-married women to wear a yellow veil,—a colour which was confined entirely to matrons; and those who were employed in the Games of the Circus were distributed into divisions, each of which were dressed in an appropriate colour. The colours mentioned are *color prasinus*, green: *rufatus*, orange: *venetus*, grey, or perhaps a light blue and white.

The following seem to be the principal substances from which these colours were obtained. *Alkanet*, or the roots of *Anchusa tinctoria*, the blood of birds; the *Genista tinctoria*, or dyers' broom; madder; woad; the bark of the walnut, and pods of the Egyptian acacia.

These are the chief substances which are mentioned to have been employed by the Romans; many more were very probably in use at that time. Indigo (*Indigum*

Manufac-
tures.

nigrum) is mentioned by Pliny, and although some doubts have been entertained respecting the true nature of this substance, some supposing it to have been Indian ink, yet it is very probable he meant the indigo of the Moderns, from the purple smoke which he describes as emitted when set on fire. It is also doubtful whether this substance was employed in dyeing, or merely as a pigment. See Indigo Works.

The two substances, woad and madder, are used to considerable extent in the present dyehouses. The first origin of woad as a dye we cannot find any mention of, but its properties were very probably known at a very early period. Madder is mentioned by Dioscorides; at least he describes a plant called *ereuthodanon*, which is supposed by Beckmann to be the same.

The fruit he states is at first green, then red, and lastly black. The thin long roots, he further states, were employed in dyeing, and on that account the cultivated kind was reared with much benefit in Galilea, around Ravenna in Italy, and in Caria, where it was planted either among olive trees, or in fields destined for the purpose.

Scarlet dye.

Among the most important steps in dyeing may be classed that of the discovery of the scarlet dye. The origin of the term scarlet, from which we might judge of the time of its invention, seems very uncertain. Stiler says scarlet is entirely German, and compounded of *schor*, the fire, and *lacken*, cloth, so that its real signification is fire-cloth, or fire-coloured cloth; while Reiske, on the other hand, considers that the word is originally the Arabic *scharal*, which means the kermes dye. There is no doubt that the colour must have been known at a very early period. Beckmann quotes a passage from the *Historica Gebrica* of Pontanus, in which it is stated, that Henry III., in the middle of the XIth Century, conferred upon the Count of Cleves the Burg-graviate of Nimeguen, on condition of his delivering to him yearly three pieces of scarlet cloth made of English wool.

Of the preparation and goodness of the ancient scarlet we certainly know nothing, but, as we find in many old pieces of tapestry of the XIth Century, and perhaps earlier, a red which has continued remarkably beautiful even to the present time, it cannot at any rate be denied that our ancestors have not extolled their scarlet without reason.

Discovery
of cochineal.

This colour was, however, very different to that which bears its name in the present day, the former having been obtained from kermes, while the latter is procured from cochineal, and exalted in brilliancy by the application of a particular mordant. The insect to which we give the name of cochineal was unknown in Europe before the discovery of America. When the Spaniards first visited Mexico, in the year 1518, they observed that the inhabitants of that Country employed cochineal for communicating a colour to some parts of their domestic utensils, ornaments, &c., and also as a dye for cotton. The Europeans were so struck with its beauty that an account of it was transmitted to the Spanish ministry, who, accordingly, in the year 1523, ordered the Cortes to adopt proper measures for increasing the produce of a commodity which appeared to be of the utmost value as a dye.

Discovery
of Cornelius
Drebbel.

The tincture of cochineal alone yields a purple colour not very pleasant, which may be made into a most beautiful scarlet by a solution of tin in *aqua regia*. Mr. Ruhlenskamp at Bremen, one of the most learned dyers in Germany, and who has studied with great care every new improvement of the Art, gives the following

history of the modern scarlet dye. The well-known Cornelius Drebbel, who was born at Alkmaar, and died in London in 1634, having placed in his window an extract of cochineal, made with boiling water, for the purpose of filling a thermometer, some *aqua regia* dropped from a phial broken by accident which stood above it, and converted the purple dye into a most beautiful dark red. After some conjectures and experiments, he discovered that the tin which had been dissolved by the *aqua regia* was the cause of the change. He communicated his observation to Kuffelar, an ingenious dyer at Leyden, who was afterwards his son-in-law. The latter brought the discovery to perfection, and employed it some years alone in his dye-house, which gave rise to the name of Kuffelar's colour. In the course of a little time the secret became known to an Anabaptist called Gulich, and also to another person of the name of Van der Vecht, through whom it became known to the celebrated Giles Gobelin, at Paris, who there erected a large dye-house. About the year 1643 a Fleming, named Kepler, established the first dye-house for scarlet in England at the village of Bow, near London, on which account the colour was called at first Bow dye.

(757.) In England the Art of dyeing now began to excite some attention. At a meeting of the Royal Society on the 30th of April, 1667, Dr. Hook was appointed to translate into English a Work entitled *Plictho*, which had been published about a century before in Italy. At the same meeting Sir William Petty, one of the earliest and most active Members, in consequence of a previous request of the Society, laid before them *An Apparatus to the History of the Common Practice of Dyers*, which was afterwards printed in Dr. Spratt's *History of the Royal Society*, and seems to have been the first Work published in the English language on the processes and operations of dyeing. Nearly two years afterwards Mr. Boyle presented to the Society an account of his experiments on colours. Dr. Hook, at a meeting of the Society on the 11th of November, 1669, produced a piece of calico dyed by a method invented by him; he was in consequence directed to pursue the inquiry with respect to other colours, and accordingly in the following month he procured another piece dyed with yellow, blue, green, and purple, which he said might be washed with warm water and soap without removing the colours. From this time, nothing of importance seems to have been done by men of Science in this Country towards the improvements of the Art of dyeing or calico-printing for nearly the space of a century.

In France the minister Colbert, anxious to extend the commerce and manufactures of his Country, which had languished during the stormy administrations of Richelieu and Mazarin, turned his attention particularly to the Art of dyeing. He established several manufactories, and invited the most skilful artists to superintend them. It is remarkable that those of Vaurobais and Sedan were entitled, in the letters patent, "Manufactories of Fine Cloth after the Dutch and English fashions." In 1762 he published a Table of instructions for dyeing, under the title of *Instruction Générale pour la Teinture des Laines et pour la Manufacture des Laines de toutes Nuances, et pour la Culture des Drogues qu'on y emploie*. This Work was of great importance, as it was not only intended to diffuse information, but as a legislative act to control the dyers in their operations.

Mechanical
Processes.

Progress of
dyeing in
England.

Progress of
dyeing in
France.

Manufac-
tures.

Dufay's
Works on
dyeing.

In the year 1739 Dufay published a new set of instructions under the administration of M. D'Orry. He appears to have been the first who entertained just notions of the true nature of colouring substances, and the cause of their adhesion to stuffs when dyed. In his *Observations Physiques sur le Mélange de quelques Couleurs dans le Teinture, Mém. de l'Académ.* 1737, he observes, that colouring particles are naturally disposed to adhere more or less firmly to the filaments which receive them, and he remarks that without this disposition stuffs would never assume any colour but that of the bath, and would always divide the colouring particles equally with it, whereas the liquor of the bath sometimes becomes as limpid as water, giving out all the colouring matter to the stuff, which he considers to indicate that the ingredients have less attraction for water than for the particles of the wool. He appears, however, to have had no idea of the important cause of the permanency of colours, which arises from the use of mordants or the interposition of a suitable basis, having a particular attraction for the colouring matter and dyeing substance, and acting as a bond of union between them. He examined with great sagacity certain processes, and established the surest methods that could at that time be employed for determining the goodness of colour, which he did in an easy and comprehensible manner. His labours on the whole entitle him to the gratitude of posterity, as he may justly lay claim to the merit of having laid the foundation of the true theory of dyeing.

Hellot's
Works on
dyeing.

We are indebted for one of the best practical Treatises on the Art of dyeing wool and woollen cloths to Hellot, who succeeded Dufay. This Work is valuable for the accuracy with which the numerous processes are described: he is said, however, to have suffered himself to be misled by vague and groundless hypotheses on the cause of the adhesion of colouring particles to the substance dyed, the action of mordants, and the difference between the durable and fading dyes. In all the processes of dyeing he conceived that a sulphate of potash was formed, and that this salt, being sparingly soluble in cold water, and little affected by air or light, first dilated the pores of the stuff, thus preparing it for the reception of the colouring particles, and afterwards wedged these particles so closely together that it became impossible for them to make their escape. This hypothesis, which was evidently not countenanced by sound reasoning any more than by fact, was admitted without proof, and regarded for a considerable length of time as the true cause of the adhesion of the colouring principle to stuffs. Notwithstanding, however, the erroneous views of Hellot, the inferences which he deduced from them were not without practical utility, and many of the processes which he recommended may be followed with the same advantage as if they had been derived from the most scientific principles.

It is surprising that Macquer, who was an excellent Chemist, and among the first who entertained correct ideas of the nature of Chemical affinity, should have been led away by the hypothesis of Hellot. He remarks, in his Treatise on dyeing silk, "I shall now explain the action of mordants, and unfold the causes of durable and fading dyes; but this subject has been treated with so great sagacity by Mr. Hellot, that I shall refer the reader to him."

Bergmann.

Bergmann seems to have been the first who referred the phenomena of dyeing entirely to Chemical principles.

Having dyed some wool and silk in a dilute solution of indigo in sulphuric acid, he explains the effects he observed in the operation, by the blue particles having a stronger affinity for the particles of the wool and silk than for those of the acidulated water; he remarks that this attraction of the wool is so strong as to deprive the liquor entirely of the colouring particles, and that the weaker attraction of the silk can only diminish the proportion of those particles in the bath; and he shows that both the durability of the colour, and the degree of intensity it is capable of acquiring, depend upon the degree of those attractions. Dufay had advanced thus far, but overlooked the importance of his one simple fact in the search for more recondite and complicated causes.

Mechanical
Processes.

The peculiar action of mordants remained still unexplained, except on the wild hypothesis of Hellot, till our Countryman, Mr. Keir, the ingenious translator of Macquer's *Chemical Dictionary*, suggested that, in dyeing, the earth of alum was precipitated, and in this form attached to the material prepared or dyed. Macquer soon afterwards adopted the opinions of Bergmann and Keir, and in the second edition of his *Dictionary*, under the article Dyeing, published in 1778, treated the subject in a more extended manner, and proved that these were the just conceptions of the nature and uses of alum, and of different metallic solutions as mordants in dyeing.

The successor of Macquer to the honourable appointment of superintending the dyeing establishments of France was Berthollet, a man of great scientific attainments. In a series of Memoirs inserted in the Transactions of the *Académie*, the *Annales de Chimie*, and *Journal de Physique*, he has examined various points of the Chemical theory of the Art of dyeing, and almost all his labours have been since directed to this object. In 1791 he published his *Elements of the Art of Dyeing*, in two vols. 8vo., a Work which has contributed more to the progress of the true theory and the general improvement of the Art than any other Treatise whatever. This Work has been translated into English by Dr. Hamilton, and a second edition of the original, with considerable additions, appeared in 1803.

In England, owing to the want of support of the Legislature of the Country, the Art of dyeing did not make so much progress as in France. We must not, however, forget to mention the labours of Dr. Henry, who communicated to the Literary and Philosophical Society of Manchester a Paper "On the Nature of Wool, Silk, and Cotton, as Objects of the Art of Dyeing, on the various Preparations and Mordants requisite for these different Substances, and on the Nature and Properties of Colouring Matter." This Paper is replete with new and ingenious views of the nature and objects, and of the principles of the combinations employed in the various processes. Dr. Henry first pointed out the peculiar nature of the aluminous mordant of the calico-printers; he showed that by double decomposition an acetate of alumina was formed, and explained its superiority over the sulphate of alumina, or the substitution of a volatile vegetable acid in lieu of the sulphuric.

Dr. Bancroft, in the year 1794, published his *Experimental Researches concerning the Philosophy of Permanent Colours, the best means of producing them by Dyeing, Calico-printing, &c.* This Work, as the title indicates, is rather an experimental than a practical Treatise; it contains, however, much valuable information, which the practical dyer may apply in many cases

Dr. Henry
Dr. Bancroft.

Manufac-
tures.

with considerable advantage, and it is also useful as containing a history of all the different substances of which it treats, and an account of the labours of Macquer, Dufay, Hellot, Berthollet, and others in this department of Science. Dr. Bancroft first pointed out the true action of tartar in the process for dyeing scarlet, and clearly proved that the nitro-muriate of tin, or any solution of tin alone, produced a crimson only, and that the addition of tartar produced a scarlet, by the conversion of a portion of the crimson colouring matter of the cochineal to a pure yellow. On this observation he founded an improvement in the scarlet dye, which consisted in communicating to the cloth, by means of quercitron bark, and any suitable mordant, such a shade of yellow as would produce, with the crimson of the cochineal, a pure scarlet. By the introduction of the quercitron bark Dr. Bancroft has rendered a most important and lasting service to dyers, as it is now become of so general and acknowledged utility as to supersede almost every other kind of yellow colouring matter whatever.

We must not conclude this account of those whose labours have advanced the Art of dyeing without mentioning the name of Dr. Ure, of Glasgow, to whom we are indebted for a translation of Berthollet's second edition of his Chemistry, with very useful illustrative notes and engravings, from which Work much of the information contained in the following section is derived. See also Packer's Dyer's Guide.

Theory of Dyeing.

(758.) Some Chemists have endeavoured to establish the phenomena of the change and variety of colours produced by the action of different substances upon each other, as witnessed in most of the operations of dyeing, upon the principles of colour laid down by Newton, viz., the decomposition of the rays of light by the absorption of a portion of its constituent colours and reflection of another. It does not appear, however, that Science can thus far be brought to the aid of this Art; but, as Berthollet very justly remarks:

Berthollet's
theory.

"Whatever may be the physical cause of colours, the colouring particles, which it is the object of the Art of dyeing to apply to stuffs, are known to possess Chemical properties, distinguishing them from other substances dependent on the affinities which their particles collectively exercise, as well as on the reciprocal action of these particles, and on their constitution, which disposes them, more or less, to assume the solid or the liquid state."

By virtue of these properties they dissolve in different liquids; they combine with acids, alkalis, oxides, with some earths, and especially alumina; they frequently precipitate the oxides and alumina from the acids which held them in solution; in other circumstances they even form super-compounds with the salts; sometimes they unite immediately to the stuffs; more frequently they form with these substances a combination much more intimate through an intermedium, or even they do not combine with it, except through the intermedium; the intermedium modifying their colour, their other properties, and even their composition.

Difference
of affinity
of colours

The difference in the affinity of the colouring particles for wool, silk, and cotton, is sometimes so great, that they refuse to combine with one of these sub-

stances, whilst they combine very well with another; thus, cotton takes no colour in the bath that dyes wool scarlet. Dufay got a piece of stuff made, the warp of which was wool, and the weft cotton; he passed this stuff through the fulling-mill, to ensure the same preparation to the wool and cotton; but the wool took the scarlet dye and the cotton remained white. It is this difference of affinity which makes it necessary to vary the preparations and the processes according to the nature of the substance which we wish to dye of a particular colour.

Mechanical
Processes.
for different
substances.

If the effects of the intermedia employed in dyeing, and the fixation of the colouring particles on a stuff by itself, or by means of an intermedium, be owing to the combinations which are formed, we must still refer to Chemical combination the changes produced by acids and alkalis in several vegetable colours, which Chemists employ for verifying the nature of different substances. We may compare the resulting compounds to neutral salts, which possess qualities distinct from those of their components, but in which one of the components may be in excess, so as to cause its properties to predominate. This state of combination is observed between the colouring particles of cochineal and the acidulous tartrate of potash, or cream of tartar. On evaporating slowly a solution of this salt in a decoction of cochineal, crystals are formed, which retain a fine ruby colour, much more intense and more lively than that of the liquid in which they were formed.

The reciprocal action of acids and alkalis being much greater than that which they exercise in particular on the colouring particles, they can mutually saturate each other, and then the resulting compound has little effect on the colouring particles; so that the changes which had been produced by one of the substances disappear, when it is neutralized by an antagonist substance.

Blue colours are not the only ones which can pass to red by the agency of acids, and to green by that of alkalis; most of the red colours, that of the rose, for example, are exalted by acids, and pass to green by alkalis; and some green colours, such as that of the decoction of burdock, and the green juice of the buckthorn berries, (*Rhamnus catharticus*), according to Becker, redden also with acids.

Action of
acids upon
colours.

This property, common to the most ordinary colours of vegetables, appears to prove that there is a close analogy between the greater part of their colouring matters; nor is it without foundation that Linnæus thought the red colour owing to an acid, of which he maintained the existence; but there are also several vegetables which contain a free acid, without possessing a red colour.

In the combination which the colouring molecules form with the stuff, they preserve only a part of their original properties; on being associated with alumina, with the oxides, and some other substances, they are somewhat modified; but the properties of the latter combinations are further modified when they unite with the stuff.

These modifications are analogous to what is observed in other Chemical combinations; but they are subject to a peculiar degradation from the action of air and light; sometimes, on the contrary, they receive from these agents a new lustre, or a different shade; there are also agents which, after combining with the colouring particles, alter the colour which they first produced,

Manufactures.

making it pass to yellow, and then destroy it; such, in particular, is oxygenated muriatic acid; it acts by means of the oxygen which it yields, and, consequently, differs in nothing except intensity from that of the atmospheric air.

It follows, from what has been stated, 1. That the colouring molecules have affinities which produce their solution and their combination, the effects of which, combining with those of their own constitution, form the differences that distinguish them from each other.

2. That they unite directly with the stuff, or by the aid of an intermedium; but the stuff has relations with them according to its nature.

3. That, in combining with a substance, they experience a change which modifies their colour, besides the modification resulting from the shade peculiar to the substance to which they combine.

4. That the colouring molecules differ not only from one another, by these different dispositions, but likewise by the ulterior changes which they may suffer from the action of other substances, and particularly from that of the air and light.

Of Mordants.

Mordants.

(759.) Of the numerous dyes with which we are acquainted, few can be applied to either animal or vegetable fibre, without some preparation beyond that of cleansing the stuff and immersing it in the dyeing-liquor. When colours can be fixed upon cloth without any previous preparation, they are called *substantive colours*. When they cannot be so fixed, but require the interposition of a third substance, they are called *adjective colours*, and the substances interposed are called *mordants*. Sometimes substances are employed merely with the view of changing the shade of colours, whose action is different to that of mordants. These are termed by Berthollet *alteratives*.

Mordants merit the greatest attention. It is by them chiefly that we diversify the colours, give them more brilliancy, fix them on the stuffs, and render them more durable. A mordant is not always a simple agent, but in the mixture composing it different combinations are sometimes formed, so that the substances which have been employed do not act immediately, but by the resulting combinations. Sometimes the mordant is mingled with the colouring particles; sometimes the stuff is impregnated with it before being exposed to the dyeing-bath. On other occasions these two methods are combined. We may dye in succession with liquors which contain different substances, the last of which acts only on the parts with which the stuff has been imbued by the preceding operation. One solution, which is to yield its basis to the stuff, has need of heat; another requires the operation to be made in the cold. The mordant is frequently an oxide; in which case its properties may vary, not only according to its actual condition, but also according to the action of the substances with which it is associated, and even according to the circumstances of the operation. It is by the determination of all these conditions that Chemistry can particularly direct the Art of dyeing, can establish its processes in a constant manner, removing from it whatever is useless or prejudicial, and transferring to one kind of dyeing what is found efficacious in another.

The substances employed as mordants should, therefore, furnish a base which attaches itself to the stuffs and to the colouring particles, and which resists their

re-dissolution and destruction. As to those substances, however, which occasion merely some modifications in the colours, it is sufficient for them to be retained in small quantity in the combination formed between the stuffs, the mordant, and the colouring matter. Hence, although alteratives act equally by combining, they should be distinguished from mordants, which serve to fix the combination.

Acids can, in general, dissolve the colouring substances, but as they do not themselves possess the property of combining with the stuff, they cannot serve as bonds of union; on the contrary, they usually carry off the colouring particles which had been retained by the stuff, and they contribute to the colour which is fixed, only in the quality of alteratives, by uniting in small quantity to the coloured combination.

Potash, soda, and ammonia, cannot serve as intermedia to fix the colouring substances on stuffs; but they may, as well as acids, effect the solution of colouring substances on which they have an action. Their affinity with the stuffs should also tend to co-operate their solution. It is only as alteratives that these alkalis can enter into coloured combinations. If they produce some precipitation in the watering solutions of colouring substances, it must be merely by separating a body much more soluble from another in itself slightly soluble, or by occasioning some change in a substance of somewhat unstable composition. The other alkalis, namely, lime, barytes, strontites, and magnesia, which possess little solubility, or a much greater tendency to solidity, appear fitter to serve as mordants. In fact, these alkaline earths have sufficient affinity to form, with colouring substances, combinations which are precipitated from their solution; but they considerably affect their colours by their alkaline properties. They possess too weak an affinity to enter into an insoluble combination with the stuffs; so that, far from promoting the union of the colouring particles, on the contrary they obstruct it, forming insulated precipitations.

The body which possesses in an eminent degree the properties suitable for a mordant is alumina. Insoluble when it does not experience the action of acids or alkalis, it has a strong disposition to combine with the colouring particles; it does not act on their colours as the alkalis do, but it preserves very nearly their natural hue. It separates also much more easily from the acids which hold it in solution than the alkaline bases do.

Metallic oxides possess such an affinity with several colouring particles, that they abandon the acids which kept them in solution, to precipitate in combination with the colour. On the other hand, all the oxides possess the property of combining with animal substances; which several combinations may be formed by mixing with the metallic solutions an alkali saturated with the animal substance.

The oxide of tin surpasses all the others in its property of becoming fixed on woollen and silken stuffs, but especially on the former. It readily abandons the acid which holds it in solution to combine with them, so that it is sufficient to impregnate wool and silk with solution of tin, although they should be then thoroughly washed; a process which does not answer with other metallic solutions.

Tin slightly oxidized has, in reality, only an ashy colour. But since it has a great affinity for oxygen, it takes enough of it in the ordinary solutions to pass to the white colour; or it may complete its oxidizement,

Mechanical Processes.

Action of acids as mordants.

Alkalis.

Alumina.

Metallic oxides.

Oxide of tin.

Manufactures.

Oxide of zinc.

even during the operations of dyeing. It retains its oxygen with force, and hence, when highly oxidized, its oxygen exerts but little action on a colouring matter. The oxide of zinc appears to possess analogous properties, but it has much less affinity with stuffs and with colouring particles, while, on the other hand, it retains the acids more powerfully, and is thereby much less fit for a mordant.

The affinity of the oxides for substances of a vegetable nature appears to be much weaker than for animal substances, whence it happens that metallic solutions are not well adapted to serve as mordants for colours in cotton and linen. An exception must, however, be made in favour of the oxide of iron, which may be applied in a very solid manner to these substances, even when it is precipitated from its solutions. To this purpose Chaptal makes an interesting observation. He states that a solution of iron disturbed by precipitation may be cleared up by moving cotton and linen through it. We must, however, observe that the oxide of iron differs in colour according to its state of oxidation; and that the action which it exercises on the colouring substance varies, as we shall see, according to that state. The oxide of copper has also some affinity for linen and cotton, so that its solutions may be employed in some processes, and oxide of manganese possesses a similar property.

It follows from what has been stated, 1. That the acids and the alkalis are not fit for mordants, that is to say, for intermedia or bonds of union between the stuffs and the colouring substances, although those of sparing solubility can produce species of lakes with colouring matters. 2. That of all the earthy substances, alumina is the one eminently endowed with the properties of a mordant, from its affinity with colouring substances and with stuffs, and from its feeble attraction to acids. 3. That among metallic substances we must distinguish those that afford a white base to the colouring substances, and those which affect the colouring matters by their own colours. Among the former, which are fit for light and splendid colours, the solutions of tin hold the first rank, from the affinity of its oxide for the stuffs of an animal nature, and for the colouring substances, as also from its weak attachment to acids. The force with which it retains oxygen contributes to its qualities. Among metallic substances, whose colour produces modifications, iron is of the most extensive employment, but its effects vary according to its state of oxidation.

When the colouring particles have precipitated an oxide from its solvent, the latter has usually the power of dissolving a portion of the combination of the colouring substance with the oxide, and the liquid remains coloured, although the precipitation may be facilitated and rendered more complete by the presence of the stuff. The effects depend, therefore, in part, not only on the proportion, but also on the species of acid which acts as a solvent to the oxide. This observation is applicable to acids which hold alumina in solution; but the acids, alkalis, metallic solutions, and even the neutral salts, may serve as alterants.

By varying mordants we greatly multiply the shades attainable by one substance, especially with the co-operation of alterants. The same effect may also be produced by the method of applying mordants. Thus we obtain different effects by impregnating a stuff with a mordant, or by mixing the mordant in a dyeing bath, by making the operation with heat or cold, with the continued

contact of air, or without its intervention, by means of a solution in a strong acid, or of one in a feebler or more volatile acid. Mechanical Processes.

Dyeing favours the combination of the bases which have an affinity for the stuff, because the water which produces the solution resists, by its own affinity, the action of the stuff that tends to bring it into a solid state. But the circumstances by which we ought to be regulated vary according to the qualities of the stuff, which, by a disposition whose cause cannot be assigned, requires sometimes the aid of heat, whilst a stuff of a different nature combines better in the cold. Finally, the processes which a stuff should receive in succession, to attain the proposed end, sometimes decide the choice of the solution of the mordant and the manner of applying it. This is particularly observable in reference to cloths for calico-printing, which should be able to pass through several operations without receiving injury from any of them.

Astringents.

(760.) We have now to speak of another class of agents which are very important in obtaining some colours, particularly black. The name of astringents is applied to those substances which have the property of giving to iron the power of decomposing water, and forming by this means a solution of iron, which passes from blue or violet to black. The most important substances of this class are

Nut galls.
Oak bark.
Logwood.
Sumach.

On mixing a solution of iron with an infusion of any of these substances, the mixture becomes black, and will give to silks and stuffs the deepest and most indelible black colour.

The shade of black produced by these different substances varies, however, a good deal, which has led many to consider the astringent property not owing to an individual principle. Dr. Bancroft is of that opinion; and he remarks, on this subject, in his very excellent Treatise on colours, "I have invariably applied the name of astringent to those parts of vegetable dyeing drugs which are found to produce colour with an earthy or metallic base, and I have never been able to discover any good reason for doing otherwise in regard to those vegetable matters which afford ink or black dye with iron,—matters indeed which are extremely various in their other properties, and even in the sorts of black which they produce; though Chemists have, I think, improperly confounded most of them under the general denomination of astringents,—a term which may be unobjectionable, as signifying acerbity in vegetables, but not as indicating or being invariably connected with any such property of matter as they have been even supposed to possess, that of producing black colour with iron." Dr. Bancroft's theory.

Berthollet was of a decidedly different opinion, as may be learnt from the following remarks: "If gallic acid, the different species of turmeric, and several other colouring substances, such as logwood, Brazil wood, and madder, afford, with solutions of iron, blacks more or less deep, there must be something in common in the mode of acting of these substances, whatever may be in other respects the difference of their properties."

Berthollet, together with Lavoisier, Vandermonde,

Effects by varying mordants.

Manufac-
tures.Experi-
ments of
Berthollet,
Lavoisier,
&c.

and Fourcroy, was directed by the French Academy to make experiments on the different astringents, and to report on the subject. The substances upon which they instituted the experiments of comparison were galls, oak bark, rasping of heart of oak, the external part of oak, logwood, and sumach. They estimated the quantity of the astringent principle by the quantity of sulphate of iron which a solution of each would decompose, and afterwards by the weight of the black precipitate which was formed.

The results were as follows :

	drs.	grs.
Decoction of two ounces of galls required to saturate it	3	61
Weight of the precipitate	7	24
Ditto of oak bark	0	18
Weight of the precipitate	0	22
Ditto of heart of oak	1	24
Weight of the precipitate	1	24
Ditto of logwood	1	48
Weight of the precipitate	2	12
Ditto of sumach	2	18
Weight of precipitate was not ascertained.		

These eminent Chemists concluded, from the results of their investigation, that the quantity of astringent substances required to give a black colour of equal intensity, to an equal weight of the same cloth, were proportional to the quantities of astringent principle which had been estimated in each kind by the foregoing experiments ; but that the black obtained by the different parts of oak did not resist tests or proofs as well as that produced by galls. It appears also that logwood alone was incapable of producing so intense a black as galls or oak, nor was the colour so permanent.

It is found that the mixture of two of these substances yields a more intense black than when one is used singly. Thus, in practice, a decoction of logwood is added to that of the galls. It is also advantageous to fix a blue colour on stuff which is to be dyed black.

Other uses
of astrin-
gents.

The use of astringents is not confined to dyeing black colours ; they exert on several colouring particles an affinity which serves to fix them on stuffs, and to communicate stability to them. In this point of view they may be compared to mordants ; but as they possess in themselves a colour which has a tinge of yellow or dun, and as the effect of one colour must be to modify and darken that peculiar to another colouring substance, the use of astringents as mordants does not suit bright colours, particularly those of little intensity.

Substances used in Dyeing.

(761.) These substances may be divided into two principal classes, viz., the vegetable and mineral, to which are to be added, however, some of animal origin and various chemical compounds. In the following arrangement,—in consequence of the difficulty in some cases of drawing a line of distinction between the classes, or rather of deciding upon the class to which some particular substances should be appropriated,—we have included those of animal origin in the first division, and the chemical compounds, which are generally mineral, in the second. The substances are arranged alphabetically in each division, with the purpose for which they are employed, the substances from which obtained, and any other information on the subject of each which appeared of importance

(762.) Vegetable and Animal Colours used in Dyeing.

Mechanical
Processes.Various
dyeing sub-
stances.

Annatto is employed in dyeing silk and cotton yellow: it is produced from a reddish pulp which covers the seeds of the *Pixa orellana*, a plant which grows spontaneously in different parts of Guiana. This substance is in more common use on the Continent than in this Country.

Archil is generally employed by dyers to give bloom to other colours ; it is obtained from a whitish lichen which grows upon rocks in the Canary and Cape de Verd Islands ; it yields a rich purple tincture, extremely beautiful.

Argol, tartar, or *supertartrate of potash*, is employed in producing scarlet and some other colours, and for various purposes in dyeing. It is a crystalline substance deposited in wine-casks during the fermentation of the wine from the juice of the grape, in which it exists in considerable abundance. Cream of tartar is the same substance, freed from the colouring and other extraneous matter.

Barwood is employed with the aluminous mordant in giving a yellowish brown red to wool and cotton. The colour is, however, rather fugitive on the latter. It is obtained principally from Angola, in Africa.

Blood, generally that of sheep, is employed in dyeing Adrianople red, and some other colours.

Bran is employed to loosen and remove colouring matter, and, in some cases, to alter its hue.

Brazil wood is employed for dyeing red colours. It is obtained from the heart of a tree, which Linnæus describes under the name of *Cæsalpinia crista*, and is a native of Brazil, from which it derives its name.

Cæsalpinia sappan is employed for the same purposes as Brazil wood, to which it is nearly allied in properties.

Cam wood is also employed in dyeing red. It is obtained from a tree imported from Africa by the Portuguese. *Jamaica brazilleto* and *Bahama brazilleto* probably belong to the same species, although they are usually classed as different. They afford the least valuable of the dyeing woods, and are only employed in producing inferior and fugitive colours.

Cochineal is employed for dyeing various shades of red : it is obtained from the female insect of the *Coccus cacti*, found on the *Cactus coccinellifer* and *Cactus opuntia*, natives of South America, the West Indies, and other tropical regions. This is one of the most important colours used by dyers.

Cudbear is employed for dyeing various shades from pink and crimson to Mazarine blue. It is manufactured in this Country from archil.

Galls are employed in dyeing as astringents. They are excrescences produced on the *Quercus infectoria*, a species of oak growing throughout Asia Minor, but chiefly exported from Aleppo. The gall grows on the shoots of the young boughs, and is produced by an insect, the *Cynips quercusfolii*, which punctures the young shoot with its sting, and deposits its egg in the puncture. The egg is soon hatched, and the irritation of the maggot feeding on the plant produces the wen or gall-nut.

The gall or bile of animals is employed by some dyers and scourers in preference to soap for cleansing clothes. It is a bitter yellowish fluid, secreted by the liver, and found in the sac usually called the gall-bladder.

Gums, Senegal, Copal, &c., used chiefly in calico-printing.

Manufac-
tures.

Indigo is employed very largely in dyeing blue colours. It is obtained from a plant, the *Indigofera tinctoria*, or Indigo-bearing plant, a native of the East Indies, and is exported here both from the East and West Indies, and America. (See Indigo Works.)

Kermes is employed in dyeing scarlet. The use of this dye has been almost entirely abandoned in Europe since the introduction of cochineal. It is produced from an insect (*Coccus ilicis*) found in several parts of Asia and in the South of Europe.

Lac is employed for dyeing red and scarlet. It is of animal origin, being produced by the *Coccus lacca*, a small winged insect, and is generally deposited on the small branches of the *Croton lacciferum*, a tree which grows in India. As an article of commerce lac is known in Europe under the appellations of stick lac, seed lac, and shell lac. The first is the lac in its native state, as it is found adhering to the twigs. The seed lac is a yellowish hard resinous substance, which remains after the red colour of the stick lac has been extracted; and the shell lac is produced from the seed lac by putting it into long bags of cotton cloth, melting it over a charcoal fire, and straining it through a cloth.

Logwood.—The principal consumption of this substance is for dyeing black and various shades of greys. It is also employed very extensively for different compound colours, and there is, in fact, no colouring matter with which we are acquainted capable of affording so great a variety of dyes, although this advantage is much diminished by the want of permanency. This substance is the wood of an Indian tree (*Hæmatoxylon Campechi-anum*.) For the method of preparing it for the dyer, see article Colour-mill.

Madder.—Also a very important colour in dyeing, employed to give a red colour. It is the root of a plant which Linnæus divides into two species, the *Rubia tinctorium foliis senis*, and the *Rubia peregrina foliis quaternis*, and is exported into this Country from Zealand.

Peachwood is employed in giving a maroon colour. It is obtained from a tree resembling the Brazil wood, but does not yield above one-third of the colouring matter.

Quercitron or *American bark* is employed for dyeing yellow, and was brought into notice by Dr. Bancroft, who obtained the exclusive privilege of using it as a dye, by an Act of Parliament passed in the 25th year of the reign of George III. It is obtained from the *Quercus nigra*, or black oak, a native of North America.

Safflower, *Bastard Saffron*, or *Carthamus*.—This dyeing material consists of two colouring substances, a yellow and a red. The former is of little value; the latter, which is soluble in alkalis, forms, by preparation with acids, a beautiful red pigment, sometimes used for silk-dyeing, but more commonly in the preparation of rouge. It is obtained from one or two plants, species of the *Carthamus* genus, natives of the south of Europe and the coasts of the Mediterranean.

Sumach is employed alone to give a brown and a fawn colour. Cotton stuffs, impregnated with acetate of alumina, take a durable yellow from it. It is the production of the *Rhus coriaria*, a shrub which grows in Syria, Palestine, Spain, and Portugal.

Turmeric is employed chiefly for dyeing yellow. It is of a very rich colour, and said to surpass every other yellow colouring matter in beauty. It is, however, in consequence of its slight affinity for stuffs, or the mordants which are usually employed, not by any means perma-

nent. It is obtained from the root of the *Curmuna*, a Mechanical Processes. plant growing both in the East and West Indies.

Weld.—Also employed to give a yellow colour. It is obtained from a plant (*Reseda luteola*) which grows wild in this Country, but is cultivated for the purposes of the dyer.

Woad or *Pastel* is employed to give a blue colour. It is obtained from a plant (*Isatis tinctoria*) growing in various parts of Europe and in this Country, and is cultivated with great care for the dyeing matter which it affords, and which is obtained from the leaves of the plant, collected and prepared in a particular manner. See article Colour-mill.

In addition to the above vegetable colours may be mentioned Dyer's broom, Sawwort, French berries for yellow colours; Walnut root and the outside green shell of the nuts for brown; and *Chay* and *Galium* for red. These substances are not, however, employed to any extent.

(763.) Mineral and Chemical Substances used in Dyeing.

Alumina, Sulphate of, or *alum*, is employed by calico-printers and dyers as a mordant; 100 parts are composed of sulphate of alumina 36.70, sulphate of potash 18.88, and water 44.42. It is found native in some places, but the greatest part of the alum of commerce is prepared from the schistose pyritic clays usually denominated alum ores. Alum is made at Civita Vecchia, in Italy, and also at many other places on the Continent; at Hurlett, near Glasgow, at Whitby, in Yorkshire, &c. See Alum-works.

Alumina, Acetate of, is employed in large quantities by calico-printers in the preparation of mordants.

Arsenic, Sulphurets of.—Orpiment and realgar have been applied to the purposes of dyeing a yellow colour. The sulphur is combined with these two minerals in different proportions. Realgar is of a red colour: it occurs native in Germany and Switzerland; it is also produced by art. Orpiment is produced by art, and is of a yellowish colour. Native orpiment is also occasionally found. It is of a bright lemon-colour.

Arsenic, Oxides of, are also used in dyeing, as mordants.

Copper, Acetate of, or *verdigrise*, is employed as a green colour. It is obtained by exposing copper plates to the husks of grapes, which contain a great quantity of acetic acid; the sulphate of copper, or blue copperas, the nitrate, and prussiate also, are employed in dyeing. Dr. Bancroft proposed to employ the oxides of copper as substantive colours, but they do not appear to have been adopted.

Iron, Acetate of, is much employed by calico-printers as a mordant, and in combination with other colours. The sulphate of iron, or green copperas, the muriate and prussiate also, are employed for various purposes in dyeing. The latter salt is the beautiful pigment termed Prussian-blue.

Iron, Oxides of, are employed very extensively as mordants, and constitute the basis of all black colours.

Lead, Oxides of, are used as mordants, but they are said to tarnish the lustre of the colours. The *acetate* and *sugar of lead* also are employed for various purposes by the dyer.

Mercury, Muriate of, or *corrosive sublimate*, is employed as a mordant.

Muriatic acid is employed as a solvent for some colours.

Manufac-
tures.

Nitric and *nitro-muriatic acid*, or *Aqua regia*, sulphuric, and some other acids are employed for the same purpose.

Oxymuriatic acid, or *chlorine*, whose valuable services in bleaching have been already described, is employed in dyeing as a test for the durability of colour.

Potash, *pearlash*, and *soda* are employed for various purposes in dyeing.

Tin, *Nitrate of*, is employed very extensively as a mordant. The solution of tin commonly used by dyers, termed spirit, is prepared with very dilute nitric acid, which dissolves about one-eighth of its weight of tin, previously reduced to a granulated form. The *muriate*, the *nitro-muriate*, the *murio-sulphate*, and other salts of tin, are also used very effectively as mordants.

We might enumerate many other substances used by dyers, but as the use of them is neither frequent nor important, and can be supplied by some of the substances above named, we conceive it unnecessary to lengthen our columns by the addition of them.

On the different Branches of Dyeing.

Subdivi-
sions in the
process of
dyeing.

(764.) In the Art of dyeing, as in most other processes, an advantage is derived from carrying on the works on a large scale, not only from the general principle that by the subdivision of labour, each workman, occupied with a single object, acquires celerity and perfection in his employment, but because the residuum of one process can be applied very frequently with advantage in another. From the immense extent of the Art in this Country, this principle must be adopted, and certain subdivisions into different branches had recourse to. Thus we have woollen dyers, who are occupied solely in colours obtained from cochineal, such as scarlet, crimson, orange, buff, &c., and others in dyeing purple, or royal purple: they are called grain-dyers, from the circumstance of the colouring material, cochineal, being in small grains. It ought, however, to be observed, that the term dyed in grain is applied by the public generally in a very different sense, namely, to those cloths, the raw material of which is dyed previously to being spun into thread, or at least before it is woven into cloth; and hence such dyes are usually more permanent than those which are dyed after the materials are woven into cloth. Grain dyers generally dye cloth in the piece, or in a number of pieces tacked together, and worked over a winch in a suitable copper.

There are dyers likewise who dye worsted and woollen yarn of those grain-colours, which is generally a distinct branch. The yarn is dyed in hanks upon sticks, and when in the copper, the hanks are changed end for end, so that they may be kept even, such changing being performed five or six times to each turning. There are also silk-dyers who are grain-dyers, who dye in the skein chiefly for new goods. Some silk and some mixed silk and worsted goods are dyed in the piece.

Dyeing cotton of the Adrianople, or Turkey-red, is in many cases a branch of itself, and comes nearest to what may be called grain or scarlet-dyeing upon cotton, because cochineal cannot be applied with any advantage to cotton. Cotton is, however, occasionally dyed with that material.

In dyeing woollen manufactures, another branch consists of woad-dyers, which very commonly includes the black dye on woollen cloth, as well as the blue from woad and indigo. There is the same distinction among

worsted-yarn dyers they have likewise to do slates, greys, &c. Nearly the same may be said of the silk-skein dyers. In many places, browns, drabs, stone-colours, &c., constitute a branch in woollen-dyeing. The same colours also form a branch in calico and muslin: but black in calico and muslin is a distinct branch.

The following constitute also particular branches, black hats, hats of fancy colours; fur; chip and straw; feathers; leather, Morocco and Spanish, and kid for shoes and gloves. Some other branches might be enumerated, but more detail does not seem necessary.

On the Arrangement of Dye-houses and the Apparatus employed.

(765.) A dye-house ought to be spacious, well lighted, and as near as possible to a stream of water. It should be floored with lime and cement, and provided with ready outlets for the water and spent-baths, and the whole so ordered as to ensure the utmost cleanness.

The arrangement and size of the boilers must depend on the operations for which they are intended; they should be made of copper or brass, except for dyeing scarlet, for which purpose it is better to employ boilers of tin, as well as for other delicate colours, where a solution of tin is made use of. Brass is less liable to be attacked by saline substances, and to stain the goods, than copper. In many cases, vessels of wood may be substituted for metal boilers. It is of consequence to cleanse the boilers well after each operation, and such as are of great capacity ought to have in their bottom a copper pipe with a stop-cock at its outer end, which is opened when the baths are to be emptied. Above each boiler, holes are pierced in the chimney-piece, or wall, for resting the ends of the poles, which serve to sustain the hanks of wool or silk while draining, or any stuffs, of which only small portions are to be dyed, by means of which the bath-liquor falls back again into the boiler. For piece-goods a winch or reel is employed, the two ends of which rest on two forks of iron, placed at pleasure in holes bored in the curl which supports the edges of the copper.

Several silk and cotton dyes, for which ebullition ought not to be employed, are performed in long vessels of copper or wood, called troughs or backs.

As the most part of colours applied on silk are very delicate, they require to be speedily dried, to prevent their changing. For this purpose a drying-room is provided, which is heated by means of a stove. The silk is stretched on a moveable pole called a shaker, which is hung up and agitated to accelerate desiccation. A drying-room is also used for cotton cloths which have been impregnated with a mordant. Cylinders heated by steam are now very frequently employed for drying.

When one or more pieces of goods are to be dyed the winch-reel is employed. One end of the cloth is wrapped round the reel, which being turned quickly carries round the whole piece in succession. It is then turned in the opposite direction, in order that that part of the reel which was first plunged the former time may be last at the second immersion, whereby the dyeing is rendered as equable as possible. If the pieces of goods be long enough, or if several are to be dyed of the same colour, their two extremities are stitched together, the winch is passed within, and then set on its forks.

When wool in the fleece is to be dyed there is set

Mechanical
Processes.

Dye-hot.
apparatus.

Boilers.

Drying-
room.

Winch-reel.

Wool-
dyeing.

Manufac-
tures.

over the boiler a frame-work of wood resembling a ladder with the bars placed very close together. On this the wool is laid to be drained and aired, as well as during the changing of the bath.

After silks and yarns have been dyed, it is necessary to wring them, in order to squeeze out the excess of colouring matter. This operation is performed on a cylindrical piece of wood, which is fixed at one end in a wall or to a post.

Colour-
mills.

Dye-houses very commonly contain Machinery for preparing the colours, which consist of various descriptions of mills for the purpose of reducing the ingredients into minute portions, in order that the colouring matter may be readily extracted from it. These have been already described under Colour-mill, to which we refer the reader.

On the Preparation of the Colours.

(766.) Dyeing is one of the Arts in which Machinery performs a very unimportant part in the processes; the department in which the attention and skill of the dyer is most profitably employed being that of the mixture and proportion of the different ingredients. The immense number and variety of colours, all of which require an operation peculiar to themselves, however, preclude the possibility of entering here upon this subject at a length that will be serviceable to the practical dyer. We trust, however, that the following remarks upon the composition of the principal colours may not be without interest and service to the general reader.

On Dyeing Black.

Dyeing
black.

(767.) Very few substances are known which can of themselves afford a solid black, and they have been tried only on linen and cotton. The juice of the cashew nut, or *anacardium* of India, communicates a black colour which resists even boiling with soap and alkaline leys.

The *Anacardium occidentale*, and some other shrubs, yield a dye which is nearly black, but they can be procured only in such small quantities that they are scarcely at all employed in English dye-houses, all blacks being produced by the action of astringents upon iron.

Dyeing silk
black.

A very common process for dyeing silk black in our dye-houses is to boil together, for three hours, $1\frac{1}{2}$ bushels of alder bark, 14 pounds of logwood, and 1 pound of iron filings, at the end of which time the fire must be damped. Four ounces of sulphate of copper in water are then added to the liquor, and well mixed. The silk is immersed four times in the liquor, and aired on the floor until it is cold between each time; three pounds of sulphate of iron are then added to the copper, and two more immersions given to the silk.

The drugs are left to boil as much as they will during the night, and, the next morning, the silk is again immersed four or five times, and left in the copper all the following night, the liquid being at a temperature considerably under the boiling point.

Dyeing
cotton
black.

In dyeing cottons black the goods are commonly passed through a blotching Machine to receive a mordant of acetate of iron, and galled slightly, but Sumach is used instead when galls are dear. The cotton is then passed through a bath of logwood, or of logwood and fustic, and then through sumach. They are again galled, and the same processes repeated until a full and rich black is produced.

In Manchester the dyers make a black iron liquor by

filling casks with layers of old hoop iron rusted in the air and cut into small pieces, with intermediate ones of alder bark. The casks are filled with water and left for six weeks or two months. This liquor is used after goods have been passed several times through a decoction of logwood and sumach, and through sulphate of iron. It is said that the black produced by this means is much esteemed for all cotton goods.

Mechanical
Processes.

Cotton and silk are sometimes dyed with a blue ground, but it is not found to enrich the black as in dyeing wool, where a good black cannot be attained without it.

Indigo for the ground is the richest and most common drug. A great many articles, however, have a ground of logwood, or logwood and alder bark, or of logwood and old fustic, or all these substances boiled together. Logwood has a tendency to give the black a foxy hue, which the alder bark and old fustic correct, but they must be used in small quantities for this purpose, because the dye from these will produce a soot or dead black.

Blue
ground for
dyeing
wool.

After the blue ground is thus given, the black is commonly produced by sumach, sulphate of iron, and a small quantity of verdigrise. Some dyers boil the stuffs in alum and tartar; in fact, almost every dyer has a black of his own produced by a different process, so that it is impossible to describe any decided mode of producing this colour on wool.

Of Grey Colours.

(768.) The greys being shades of black, their colours are produced by the same substances. In dyeing silk, a bath is prepared with fustic, logwood, archil, and sulphate of iron, which ingredients are varied according to the shade to be given. Thus, more archil is employed for greys that are to have a reddish cast, more fustic for those which ought to incline to a russet or green, and more logwood for such as are to have a darker grey. For the iron grey, logwood and solution of iron are had recourse to. The black grey requires the addition of a solution of alum, after which the silks are taken to the river, and then receive a bath of weld. A portion of this bath is thrown away to substitute for it the extract of logwood. When the silk has been impregnated with this, solution of iron is added in sufficient quantity, and when the desired shade is attained, the silk is washed and wrung.

Dyeing
silks grey.

Should the grey come out deeper than is desired, the silk is turned through a solution of tartar, and then through hot water, and if the colour be too much weakened a fresh dye bath is given it.

For linen and cotton, a blue ground is given to black grey, iron grey, and slate grey, but not to the other greys. All the shades require a galling proportioned to the grey which is wished to be procured. Baths of nut galls that have been previously used are often employed.

Dyeing
linen and
cotton grey

When the yarn has been galled, wrung, and dried, it is turned over sticks in a bucket full of cold water, to which a quantity of a black iron liquor with logwood is added. The yarns are worked in it in separate portions; then hung out and dried.

Another very good process consists in taking a quantity of very dilute acetate of iron, and a decoction of sumach, also very dilute. The cotton is passed in succession from one liquor to the other, till the wished-for shade is attained. The finish is given by passing the goods through water slightly acidulated with sulphuric

Manufac-
tures.

acid, otherwise the sumach gives a russet hue. By the same process with nut galls, less lively greys are attained, and the alder bark affords an agreeable one which borders on hazel.

Dyeing
wool grey.

For dyeing wool a decoction of pounded nut galls is prepared, and the sulphate of iron is separately dissolved. A bath is made corresponding to the quantity of stuff which is to be dyed, and when it is as hot as the hand can bear, the decoction of nut galls and solution of sulphate are poured into it. The wool is then immersed, and, if in withdrawing it is not found to be of a sufficiently dark shade, more of the solution and decoction are added, and thus any shade of a brown grey can be attained by adding more of the two liquors. It is, however, better for the black grey and the other deep shades to give a blue ground previously to the stuff.

The greys are very useful colours in dyeing, not only from the prevalence of the colour, but from their application to other colours which operation is called saddening or darkening.

Of Blue Colours.

(769.) The preparation for dyeing blue is not generally made in boilers as for most other colours, but in large wooden vessels termed vats, which are very commonly heated by steam, in order that a regular heat may be maintained.

Dyeing silk
blue.

Blue may be dyed with pastel or woad, but it is by no means so rich in colour as with the addition of indigo. In dyeing silk, woad is not employed, the indigo being the only colour. In preparing it, a quantity of alkaline ashes, bran, and a small quantity of madder are boiled together, which are poured into a vat containing the indigo, and all well mixed by raking. The vat must now be heated, closed, and left for about forty-eight hours, when it will, if properly managed, appear of a fine green, covered with coppery flakes and scum; the goods may now be immersed in it until the desired shade is attained.

The ashes are a solvent to the indigo, and cause by their action a more intimate mixture with the water. The use of a substance as a mordant is not required in dyeing this colour, indigo being one of the substantive colours, or rather it has a natural Chemical affinity to the silk.

In giving a deep blue to silk it is necessary to prepare it by giving it another colour as a ground, which is commonly done by a bath in archil. A blue is sometimes given to silk by means of verdigrise and logwood, but it is by no means a durable colour.

Saxon blue.

Saxon blue, so named from being discovered in Saxony, is produced from a dye composed of indigo and sulphuric acid. In making this dye Bergmann uses one part of indigo well pulverized with eight parts of sulphuric acid so concentrated that its specific gravity is to that of distilled water as 1.90 to 1.00. After twenty-four hours the indigo will be dissolved, producing a mixture perfectly black and opaque, which, by diluting with water, is fit for use. For cotton it is, however, necessary to neutralize the acid by some alkali, which is generally done by pearl ashes and lime.

Dyeing
cotton and
wool blue.

In dyeing cotton and wool a blue vat is commonly prepared of woad and indigo, by first boiling in about a gallon of water 2 ounces of potash, $\frac{3}{4}$ of an ounce of madder, and 1 ounce of bran. After it is sufficiently boiled and well settled, it is put into another copper with 4 ounces of indigo finely powdered; the liquor should be kept stirred and very hot, but not be allowed to boil.

At intervals, some lixivium of lime should be put into it, and that being cold will keep the liquor from boiling, and render the potash more active. As soon as the indigo is dissolved and properly diluted, the fire is damped and the solution covered over. In preparing the woad-mixture about 5 pounds of woad are mixed in 12 gallons of water with 1 ounce of madder and about a handful of bran, kept at about a blood-heat, and stirred for 12 or 14 hours, when the indigo prepared as above described is added to it, and the goods are immersed; the quantity of indigo which must be put into the vat being determined by the shade which the goods are required to possess. Lime is generally added to the woad-vat, but care must be taken that an excess is not made use of, or the colour of the vat will be spoiled, yielding to any substance put into it a dirty grey instead of a blue.

A very beautiful blue may be given to all kinds of goods by Prussian blue, but some difficulties have been experienced in rendering this colour permanent. In using it, it is commonly dissolved in muriatic acid, and diluted. As the Prussian blue cannot be perfectly dissolved, but only attenuated, it falls down rapidly on the stuff, and very often causes the colour to be wavy. To avoid this, the stuffs must be passed very rapidly through the solution, and the operation repeated very frequently.

A combination can be produced between the prussiate of iron and a stuff only when the oxide of iron is previously combined with the stuff so as to receive the prussic acid; but on impregnating a stuff directly with a solution of iron, in order to combine it with the oxide of this metal, inequalities are inevitable, which become very obvious when they are changed into prussiate. This inconvenience is avoided by dyeing the stuff first grey, or a deeper shade, according to the blue wished to be obtained, for in this primary dye a more uniform combination is made of oxide of iron and of astringent matter with the stuff.

The French Government, in 1801, granted to M. Raymond the sum of 8000 francs, as a reward for communicating to the Public his process for dyeing of a uniform fast and bright Prussian-blue colour. His process is as follows: He first converts, by gentle calcination, sulphate of iron into a red sulphate of iron, which he dissolves into sixteen times its weight of water, and filters. The silk, prepared as for indigo dye, is put into the solution of iron, and left there more or less time, according to the shade of blue which is wanted; it is then taken out and wrung very dry on a pole placed over the vat. It is then thoroughly cleansed by being twice bathed, plunging and agitated each time, in running water.

Dissolve in pure water heated to 167° one ounce of ferro-prussiate of potash for every twelve ounces of silk to be dyed, and when the prussiate is dissolved, add one part or even rather more of muriatic acid, stirring the mixture well. When the liquor has acquired a greenish colour, the silk must be plunged into it and stirred about for some minutes until it has received sufficient colour; it must then be well bathed and washed, in order to free it from any portion of the prussiate of iron not truly combined with it.

The silk must lastly be agitated in a vessel of water, with two pounds of water of ammonia with it, for every 100 pounds of silk, by which process the blue becomes many shades deeper and of a much richer and brighter tint, and, at the same time, is fixed more perfectly in the silks.

Mechanical
Processes.

Prussian
blue.

Raymond's
process.

Manufac-
tures.

Of Yellow Colours.

(770.) In dyeing all yellows it is necessary to employ mordants, because the affinity of yellow colouring matters for either animal or vegetable stuffs is not sufficiently strong to produce durable colours. Yellow colours, therefore, belong to that class which Dr. Bancroft has denominated Adjective Colours.

Dyeing silk
yellow.

The substances capable of giving a yellow colour to different stuffs are very numerous, but those most commonly employed are weld, fustic, annatto, and quercitron bark. For silk no other ingredient is generally used except weld. The silk must be first well scoured, alumed, and washed. A bath is made with two parts of weld for one of silk, and after one hour's ebullition it is filtered through a cloth or sieve into a vat, and when sufficiently cool to allow the hand to be plunged into it, the silk is immersed, during which operation the weld is boiling a second time in fresh water. One half of the first bath is now thrown away, and the deficiency made up by the decoction of weld from the fresh bath, and the silk again immersed. A quantity of crude pearl-ash is dissolved in a portion of the second decoction, which is added to the bath, and has the effect of deepening the colour and giving it a golden hue; the quantity of this solution added, of course depends upon the shade of yellow required. For very light shades of yellow, it is necessary that the silk should be perfectly scoured; and if a shade of green is required, some liquor from an indigo vat must be added.

Chromate
of lead.

The chromate of lead is sometimes used for dyeing silk. The hanks, if immersed for a quarter of an hour in a weak solution of acetate of lead, well washed, and dipped in a solution of chromate of potash, will in the course of ten minutes take a fine yellow colour. This article was first employed in dyeing by M. Lassaigne, who published an account of his process in 1820, since which time it has been a good deal used in this Country. From being decomposed by soap and water it is chiefly applicable to silks; by applying, however, a mordant of acetate or nitrate of lead, and passing the goods through bichromate of potash, a very beautiful and sufficiently fast yellow is now given to cotton goods in this Country.

Dyeing
cotton with
weld.

For dyeing cotton yellow with weld, the first thing is to scour it in a bath prepared with the lixivium of ashes of green wood, and then to wash it, dry it, and alum it with the fourth of its weight of alum. After twenty-four hours, it is taken out of the aluming and dried without washing. A weld-bath is now prepared of one part and a quarter of weld to one of cotton, in which the cotton is immersed until the required shade is obtained. It is then taken out of the bath and macerated for one or two hours in a solution of sulphate of copper, and afterwards immersed in a boiling solution of white soap, which, with washing and drying, completes the operation.

Dyeing
with quercitron
bark.

In Dr. Bancroft's process for dyeing yellow with the quercitron bark, 10 pounds of bark are immersed in a proper-sized vessel for six or eight minutes, and a solution of murio-sulphate of tin is added to it, and the mixture stirred for two or three minutes; the cloth must now be put in and kept in motion by two or three men at a winch; the liquor must be made to boil, which will produce, in fifteen minutes, a very good yellow. When a very bright yellow is wanted 7 or 8 pounds of solution of tin, 5 pounds of alum, and 10 pounds of bark are required for 100 pounds of cloth.

In dyeing wool with weld it must be previously boiled in mordants of alum and tartar for one or two hours; for a full yellow 4 or 5 pounds of weld will be required for 1 pound of cloth or worsted. Weld is the most common yellow dye for wool, but the quercitron bark answers very well. In using this substance it is sufficient to boil it with its own weight, or one-third more than its own weight, of alum for ten minutes. The stuff is then introduced, and the deepest shades are given at first, ending with straw-colour. Some dyers boil the stuff for one hour, or an hour and a quarter, in a solution of alum, containing a weight of alum equal to eight times that of the wool, and then dye it in a bath prepared with a weight of quercitron equal to that of the alum, till the colour be sufficiently raised. Dr. Bancroft recommends the use of a solution of tin, as we have described in dyeing cotton.

Mechanical
Processes.
Dyeing
wool yellow.

Many other receipts for dyeing yellow might be enumerated; in fact, they exceed in number those of any other colour, from the great number of vegetables which contain a yellow dye. We might mention, in addition to the above substances, annatto, sawwort, dyer's broom, camomile, fenugreek, turmeric French berries, Canada golden rod, barberry, and a variety of other substances, which have been and are employed in producing yellows of different shades.

Of Green Colours.

(771.) Little is required to be said of these colours, as they are generally produced by the simple mixture of a blue and a yellow bath, or by first immersing the goods in one bath and then in the other, the shade of green depending upon the strength of the baths and the number of immersions. It is, however, with some difficulty produced on silks, as the blue-vat is liable to spot or give a parti-colour. The silk is usually strongly alumed, well washed, and divided into small hanks of about four or five ounces, that it may be easily managed in the working. Weld is boiled as described for dyeing yellow, and prepared strong enough to give a lemon ground; the silk is then immersed and turned, with all the expedition and care possible, that the colour may be even, and when a sufficiently deep colour is obtained the silk is washed and bathed. It is then wrung and formed into hanks, and dipped skein by skein in a blue-vat, which gives it a sea-green. For the dark shades of green a little logwood is added to the liquor, and sometimes old fustic or annatto. For very dark-wavy, or bottle-green shades, a little sulphate of iron is required.

Dyeing silk
green.

In dyeing cottons green, fustic is very commonly employed; they are first passed through a decoction of old fustic and submitted to a green bath composed of fustic, indigo, and weak alum-liquor, which gives a very beautiful green, although rather fugitive. In dyeing a fast green, weld must be used, which makes it a more expensive process.

Dyeing cot-
tons green.

In dyeing wool, a blue ground is generally given by a wood-vat, light or full according to the pattern; the goods are afterwards prepared with alum and tartar, and dyed in a weld liquor. Many of the shades of green are more readily obtained by dyeing the wool first yellow with old fustic and a preparation of alum and tartar, and using the Chemic blue-vat made with the sulphate of indigo.

Dyeing
wool green.

Of Red Colours.

(772.) Cottons are the only description of goods to

Manufac-
tures.

which red colours are generally given. They require for this colour to be very perfectly bleached, or there is a liability to create stains or spots. Even the fine whites on sale are not insured against this evil, and the most careful dyers boil them in a solution of potash, and scour them with sulphuric acid; they must be then galled and well washed. After galling, the cotton must be alumed and dyed in a copper containing crop madder, which is kept boiling for three-quarters of an hour. It must be then aired and washed, and the immersion in the boiler again repeated. Some dye it again two days after, because the longer between aluming, dyeing, and drying, and between one dyeing and another, the better. The second time of dyeing, 8 ounces of madder are used for every pound of cotton. Some dyers gall it twice, and consequently dry it as often, then dye it at once in madder, having a proportion accordingly. This is a red full-bodied colour.

Adrianople
red.

The Turkey or Adrianople red, so celebrated for its beauty and permanency, is also produced by the madder root. In dyeing this colour, the cotton is boiled three hours in a liquor composed of 150 pounds of barilla, 150 pounds of fresh wood-ashes, and 75 pounds of quick lime, in 900 quarts of water, after which it is taken out and dried in the air. A liquor is then formed in the following manner: into 130 quarts of the liquor put 25 pounds of sheep's dung, and part of the intestinal liquor, previously well mixed by means of a wooden pestle, and the whole strained through a hair sieve; 12½ pounds of good olive oil is then added to the mixture, which instantly forms a soapy liquor.

Into this liquor the cotton should be worked hank by hank, often stirring it, and afterwards allowed to remain in the liquor for 12 hours, when it is taken out, lightly wrung, and dried. This process is repeated several times, until the cotton becomes perfectly white, when it is dried and galled with a quarter of pound of galls to every pound of cotton, after which it is dried and alumed 3 or 4 times.

The madder used for the Adrianople red is called *lizary*, which furnishes a dye incomparably finer than that produced by any other madder. In preparing the madder bath a quantity of liquid sheep's blood is well mixed with water in a copper, and ten pounds of *lizary* madder added for every pound of cotton to be dyed. The copper should be carefully secured, and the madder should not be quite brought up to the boiling point. In order to brighten the colour, the cotton is dipped in a lixivium of fresh wood-ashes, and 5 pounds of white soap; when the cotton has been well washed in this liquor, it is, with the liquor itself, put into a copper sufficiently large to hold it with some addition of water, and made to boil, over a slow fire, for 3, 4, or more hours, and the liquor must be covered with coarse white linen cloths, to keep as much steam in as possible. Mr. Packer observes, in his very useful Work, termed the *Dyer's Guide*, that if instead of the wood-ash, lixivium, and soap, the two reserved liquors and soap are used, the red will be much brighter than the finest Adrianople carnation.

Linen yarn takes a colour almost as bright as that of cotton, but it must be passed through a double number of leys and oils.

Of Scarlet and Crimson Dyes.

(773.) The dyeing of scarlet is performed in two opera-

tions; the first is called boiling, the second reddening. A bath is made of cochineal and tartar, which are well mixed together, and some solution, muriate or nitro-muriate of tin, added, and heat applied to the bath. The proportions of these substances should be for 200 pounds of cloth, 10 pounds of tartar, 1 of cochineal, 10 of solution of tin. When the bath begins to boil, the cloth is introduced, and made to circulate rapidly round for two or three turns; the motion is then slackened. After two hours of ebullition it is carried to the river, sifted, aired, and well ashed. For preparing the second bath, the boiler is emptied; 22 pounds of powdered and sifted cochineal are put into it, which is mixed with care and stirred. When a crust is observed to form on its surface, 28 pounds of solution of tin are poured in.

When the solution is well mixed through the bath, the cloth is thrown in, with the precaution of whirling it rapidly for the first two or three turns. It is boiled for an hour, pressing it down into the bath with rods whenever the agitation raises it up. It is then taken out, cooled, and washed in a river, which completes the operation. This same process will answer very nearly for silk or wool, except that the silk must be prepared by aluming. In dyeing crimson, the cochineal is also employed for silk, with about an equal weight of blue and white galls, and boiled in a vessel of grain tin, to which is added about one-half the weight of solution of tin.

The solution of tin employed by dyers is not always the same, some preferring the muriate, and others the nitro-muriate, of tin. Both compositions are readily prepared, by adding a muriate or muriatic and nitric acid to feathered tin, with sal-ammoniac.

Scarlet and crimson colours may be given to wool with a lac dye, which is a great deal used for carpets and hearth rugs. It is dissolved in a peculiar spirit, procured from the drysalts, to about the consistency of treacle, which is then mixed with water in a boiler, and forms the bath. To obtain a scarlet, quercitron bark is added; and for a crimson, archil.

Crimsons may be given to silk by Brazil-wood, by simply immersing it, after aluming, into a strong solution of the wood; it, however, produces a colour much inferior to that of the cochineal.

We have now described the principal processes for dyeing the simple colours; in addition to these there are an immense number of compound colours, such as violet, purple, dove-colour, pansy, amaranth, lilac, from a mixture of red and blue; the maroons, cinnamons, olive, birch, orange, capuchin, &c., from red and yellow. Hazels, snuff-colours, chestnuts, and a variety of browns, from a mixture of black with other dyes. These colours are continually changed, according to the fashion and taste of the time, and every year generally produces some new pleasing colour, sometimes the result of the accidental mixture of dyes, but more frequently that of the researches of our more Chemical and Scientific dyers.

We cannot, without exceeding the limits prescribed to this Essay, enter into a description of the numerous dyes employed in producing the compound colours. We recommend the reader who is desirous of more information on this subject, as well as on other branches of dyeing, to the following Works:

L'Art de la Teinture des Laines, by Hellot. *L'Art de la Teinture en Soie*, by Macquer. *Essai sur les Moyens de perfectionner l'Art de la Teinture*, by M. Le Pileau d'Apliny. *Instruction sur l'Art de la Teinture*, a translation from

Mechanical
Processes.

Dyeing
wool scarlet
and crim-
son.

**Manufac-
tures.** the German of Pœrner. *Elémens de l'Art de Teinture*, by Berthollet. *Philosophy of Permanent Colours*, by Dr. Bancroft. *Annales de Chimie*, various vols. *Essai sur l'Art de la Teinture*, by Bergmann. Dr. Ure's Translation of Berthollet, with notes. Packer, *Dyer's Guide*, &c. &c.

Calico-printing

(774.) The Art of calico-printing differs from that of dyeing, inasmuch that in the latter the whole piece is dyed of one uniform colour, while in the former a portion of the cloth alone is dyed of any desired pattern and colour, without affecting the remainder of the piece.

**Introduc-
tion of cali-
co-printing
into Great
Britain.**

This beautiful Art is of great antiquity, and was carried to great perfection in India. It was introduced into England, in the year 1690, by a Frenchman who, in all probability, was a refugee after the Revocation of the Edict of Nantz, and who established a small print ground on the banks of the Thames, at Richmond. A large manufactory was soon after established at Bromley Hall, in Essex, besides several others in the neighbourhood of London. About the year 1768 or 1769 it was carried into Lancashire, where the trade increased very rapidly, and is now one of the great branches of the cotton manufacture. This Art, by the aid which the advancement of the Science of Chemistry has afforded, has arrived at a state of perfection greatly exceeding that in which it had remained for many centuries in Hindustan, and may now be ranked among the masterpieces of human skill and ingenuity.

The principle upon which the process is founded is that of applying to such parts of the cloth as are required to be dyed a particular mordant, which, when the stuff is immersed in the bath, combines with the colouring matter and causes it to be permanently fixed upon it, while that on the remainder of the cloth is easily removed by boiling in hot water and bran, or by some other bleaching process; but a great improvement has been of late years introduced, termed printing by *resists* and *discharges*. In printing by resists, a substance is applied to the cloth, in the same manner as a mordant, but with this difference, that it is applied to those parts where no colour is required. The cloth is then immersed in a bath composed of a substantive colour, or an adjective colour, mixed with a mordant, which has a natural affinity for the cloth, and combines with it in all parts not influenced by the substance applied, which is of such a nature as to destroy the affinity of the colouring matter, so that when the cloth is washed the colour from those parts is immediately removed, leaving the correct impression of the pattern.

**Printing
by resists.**

**Printing
by dis-
charges.**

In printing by discharges, the pieces of goods are first passed through a mordant, and, before being dyed, a substance termed the discharge is applied to such parts as are required to be white, which has the effect of neutralizing or destroying the effect of the mordant, so that, when the cloth has been dyed, the colouring particles are rendered fugitive upon that part affected by the discharge, and can readily be removed by the usual methods of washing. In producing the great variety of colours which are given to calicoes, these various processes and methods are combined in different ways, and so beautifully arranged, that each mordant, reserve, discharge, and dye, must perform with correctness the duty assigned, as one false step would render useless the time and labour of the operation.

The action of the mordants used by calico-printers

VOL. VII.

admits of the same demonstration as of those employed in dyeing; in fact the Chemical action is exactly the same, although in practice those mordants are preferred which are possessed of great solubility, (whose acid, capable of being volatilized, is united to its base by a feeble affinity;) as these substances can be put upon the cloth in a greater state of concentration, and can be more completely decomposed upon it, more intense and substantial colours can be obtained. Their solubility gives them the further advantage of not rendering the mordant clotty, by a species of crystallization, which takes place during its desiccation on the cloth. For these reasons, the acetates of alumina and of iron, which possess these properties, are the two mordants which are most generally employed by calico-printers. They will produce with different dyes an infinite number of colours.

**Mechanical
Processes.**

**Mordants
used by ca-
lico-print-
ers.**

The acetate of alumina is made by the double decomposition of alum and the sugar of lead, but the proportions of each vary according to the circumstances for which they are intended. In general 3 pounds of alum are thrown into a barrel containing one gallon of pure soft water, at a heat of 150°, and, when dissolved, from a pound to a pound and a half of sugar of lead is added, and the whole frequently stirred for two days. On settling, a clear liquor of acetate of alumina is found at top, which contains alum in solution, and a dense white sediment remains at bottom, which is sulphate of lead, formed by the combination of the sulphuric acid of the alum with the oxide of lead contained in the acetate. Two ounces of pearl ash, and the same quantity of clean powdered chalk or whiting, are then added, which serve to decompose a portion of the salt, whose crystallization in the mordant might have rendered its employment prejudicial. The acetate of alumina is now very frequently made for the calico-printers by dissolving alum in a solution of crude acetate of lime; a gallon of acetate of the specific gravity 1.050 or 1.060 being used with two pounds and three quarters of alum. A sulphate of lime is formed, which precipitates, while an acetate of alumina, mixed with some alum, floats above; the acetate of alumina, employed as a mordant for chintz, is still commonly made by the decomposition of alum and acetate of lead. The other mordant, acetate of iron, is made by the direct solution of rusty iron in vinegar, (acetic acid;) the crude vinegar pyroligneous acid is now usually employed for this purpose in Great Britain.

**Acetate of
alumina.**

**Acetate of
iron.**

To make these mordants fit for printing, and to give them such a consistency as will enable them to dry in a figured pattern, without running into the adjoining parts, they are thickened with paste to the consistency of a jelly, by adding paste, flour, gum arabic, or senegal; 4 pounds of either of the gums being sufficient for a gallon of liquor.

Processes employed in Calico-printing.

(775.) The first process to which calicoes are subjected, after the bleaching, is that of passing them rapidly over the surface of red-hot iron, in order to remove the floss on the surface of the cloth. This operation is generally repeated twice on the side of the cloth on which the pattern is to be dyed, and once on the opposite side. The apparatus by which this is effected consists of a large cylindrical mass of iron, enclosed in brickwork, which also contains a stove for heating it; on each side of the iron are two barrels of wood, lying in a direction

**Singeing
calicoes.**

Manufac-
tures.

parallel to it, and situated below its upper surface. When the iron is sufficiently hot, viz., nearly white hot, the cloth is wound from one of these barrels to the other, which being situated below the upper surface of the hot cylinder causes the cloth to be in contact with the iron through a considerable portion of its circumference, and thus to burn off the floss, which forms a beautiful flame, fluttering on the surface of the iron. It is unnecessary to remark that the motion of the cloth must not be stopped or slackened till the piece is completed, as it would inevitably burn it; in fact, the visitors who witness this curious operation are universally in terror for the safety of the cloth, even at the speed usually employed, and which is by practice found most effective.

Padding
Machine.

The cloth is now ready to receive the mordant, which is put on either by blocks, or by a Machine termed a *padding Machine*, which consists of a frame containing two rollers, the lower of which has the pattern engraved upon it, and revolves in a box containing the mordant; the cloth is passed between the rollers, and the upper one being pressed down causes it to take the impression of the mordant. By the most improved padding Machines two different mordants may be applied at the same time by means of an additional roller, but all varieties of colour or pattern beyond this must be given by blocks.

Printing
by blocks.

The block is a piece of hard wood, generally holly, about a foot long, on which the pattern is carved, nearly as in wood engraving: it is strengthened at the back by adding a piece of thick oak. The parts of the pattern that are to receive a large body of colour, and consequently require a corresponding quantity of mordant, are given by pieces of old hat inlaid into the block, which substance is found to take up the mordant in a more uniform manner than any other material. The finer patterns are sometimes given by sheet copper, fixed on a block like fillagree work, which gives a sharper and finer line to the figured pattern. In making use of this instrument, the cloth is stretched on a long table covered with woollen cloth, and the mordant is placed in a sieve, so that the upper surface lies a little above the surface of the wires of the sieve, leaving a thin coating convenient to be transferred to the printing blocks. The mordant, when naturally colourless, is for blocking tinged with a little Brazil wood, that the workman may see the impression of the cloth, and fix the pattern with accuracy; for this wood, being a fugitive dye, does not impair the general effect. The printer, when at work, first lays the block in the sieve that contains the mordant, then applies it steadily on the cloth, and strikes it a smart blow on the back with a wooden mallet, to give a strong impression; this he repeats successively, each time carefully laying the block in the proper direction, so as not to overlap the last impression.

Drying.

In this way the patterns are impressed with one or more kinds of mordant, as may be required, after which the cloth is strongly dried in a room heated by stoves, which fixes the mordant more firmly on it by volatilizing much of the acetous acid in fumes. This is now sometimes performed by passing the cloth over cylinders heated by steam, which is a much more expeditious process, a whole piece being in this way rendered perfectly dry in the space of a few minutes. It cannot, however, be applied in all cases.

Dung bath. When the mordant is quite dry, the cloth is taken to

a cistern containing very hot water, in which cow-dung is diffused, where it is worked about, in order to dissolve out the paste and other superfluous parts of the mordant, which, not being combined with the stuff, and being diffused in the dye bath, would soil it, both by the combination which it would form with the colouring matter, and by the action of the acid which it might deposit upon it. By not carefully removing the uncombined part of the mordant a two-fold injury would accrue to the cloth, by the impoverishment of the dye bath, and by the covering of the portions which should remain white with the combination. Widmer conceives that there is formed a triple combination of the animal matter with the alumina and the cloth, which improves the beauty of the colours. This opinion, Berthollet remarks, is most probable, since water alone does not produce the effect of dunging, and he endeavoured to find other substances capable of acting in a similar manner; but the only substance he found was a matter analogous to bile. Dr. Ure considers that the action of the cow-dung in calico-printing probably arises from its seizing that portion of the mordant which is not intimately combined with the cloth, thus depriving it of the power of applying itself to the rest of the surface when diffused through the water of the cleansing bath, and thus that some animal principle in the dung, by neutralizing the excess of mordant, and possibly by precipitating it in an insoluble or inert state, protects the unmordanted spaces from being stained or coloured.

After this process, the cloth is rinsed and thoroughly cleaned, after which it is dyed in the usual way, when the whole surface becomes coloured: but the colours are much deeper on the part impressed with the mordant. The colouring matter thus enters into a triple combination with the mordant and the stuff, thereby acquiring the faculty of resisting external agents much more than when it is combined with the stuff without an intermedium. The white colour may in consequence be restored to the parts of the cloth which have received no mordant, by boiling them in water with bran. They are then exposed on a field, observing to lay on the grass the surface of the cloth that bears the colours. By the alternate repetition of these operations, the colouring matters, uncombined with the mordants, are changed in their composition, dissolved, and detached: whereas those which were actually combined, far from suffering deterioration, acquire more lustre.

This destruction of the colouring particles by exposure in the field, and ebullition with bran, is effected in the same manner as that of the colouring particles naturally combined with the stuff, which are removed by bleaching. The differences of the processes consist simply in the substitution of bran for alkalis; because alkalis would dissolve a portion of the colouring matter fixed by the mordant, and would alter its colour: whereas the bran, having a much weaker action on the substance, affects merely the colouring particles rendered soluble by the action of the air. The identity of the nature of this process with those of common bleaching led Widmer to substitute for this method the employment of chlorine, modified by an alkaline solution; the chloride of lime is now used by several English calico-printers for this purpose, but its strength requires to be varied according to the goodness of the white required. From half a pound to a pound of the dry commercial chloride to 100 gallons of water at 180° Fahrenheit may be considered as an average proportion.

Mechanical
Processes.

Dyeing.

Action of
bran in
bleaching

Manufac-
tures.
Action of
different
mordants.

The above is the simple process of calico-printing, in which all the mordants are laid on first, and the colour is given by a single dyeing afterwards, in which a great variety of shades may be produced by merely varying the mordants. Thus, for example, if one pattern be printed with the aluminous mordant alone, a second with a mixture of the former mordant with iron liquor, a third with iron liquor alone, and a fourth with iron liquor and galls, and the piece be afterwards dyed with quercitron or weld, and bleached in the usual manner, the first pattern will be a pure yellow, the second will be olive, the third of a dark drab colour, and the fourth nearly black, while the ground will remain perfectly white.

Cloth which has been thus printed with one course of colours is often subjected to a similar process for a different course with another dye, where the intended pattern requires a great variety of colours. Thus, when all the reds, purples, and browns have been given by a course of madder, the cloth, with part of the patterns thus finished, may be made to undergo a course of mordants to be afterwards dyed with quercitron for other parts of the pattern. In this case, however, much judgment is required to employ only those successions which will not act materially on each other. It might be at first supposed that when a pattern dyed red (for example) with madder, and an alum mordant, came to be immersed in a decoction of weld without any fresh mordant, that the former would not be at all affected by the latter, or at least that the effect would soon be destroyed by bleaching. But this is not found to be altogether the case; for adjective colours appear to have also their relative affinities for mordants; therefore, as fast madder red is a compound of madder and alumina, if madder has a less affinity for alumina than weld, the colour will be in part decomposed, and some of the weld will displace a portion of the madder. Hence the colour will be changed into a triple compound of madder, weld, and alumina, and the dye proportionally altered.

It appears, therefore, that in printing successive courses of colours attention should be paid to print first those whose affinities for the mordants are the strongest, and to finish with the weakest, unless (which is sometimes the case) that the change produced by the intermixture of the colours is part of the desired effect.

Topical
colours.

Another part of calico-printing is the printing of colours directly upon the cloth with the intervention of a mordant: these colours are called topical colours. In this case, substantive colours are generally used; but, if not, the mordant is mixed with the adjective colour previously to its being applied to the cloth in the general dyeing. They are applied to the cloth either by a printing Machine, resembling that employed for the application of mordants, or by blocks.

In some kinds of goods, the topical colours are applied by pencilling or painting, in which case the colour is thickened with gum arabic or senegal, and applied to the cloth with a camel's-hair brush; but in either case the cloths require no other dyeing operation, and are finished by washing and drying, for which reason it is usual to give the last parts of the pattern in this way.

Use of in-
digo in
calico-print-
ing.

Indigo is the only substantive colour used for pencilling; but here a very great difficulty presents itself, in consequence of this dye being a fast colour only in a disoxygenated state, and it is, therefore, very seldom that the pattern of a whole piece can be pencilled in indigo with the same uniformity with which some of the other colours are

given. The solution used for this purpose is usually made of a large proportion of indigo, dissolved in potash, rendered caustic by lime, to which is added orpiment for the deoxygenation of the indigo. The solution is then thickened by gum, and should be kept in a closely-stopped vessel, and no more exposed to air than is necessary for immediate use. The indigo blue is often pencilled upon figures previously dyed yellow, in order to produce a permanent green: but some little injury is done by this means to the yellow ground by the caustic alkali contained in the indigo solution.

Mechanical
Processes.

Adjective colours are sometimes mixed with their proper mordant, and used in a state for pencilling without any other preparation. Such a mixture has, therefore, the effect of a substantive colour. Thus, if a very strong decoction of weld or quercitron is added to a mixture of alum and sugar of lead, and the whole duly thickened, a yellow of a certain degree of durability is formed at once, and may be printed or pencilled on a white ground to produce a yellow, on an indigo ground to produce a green, and on a red madder ground to produce an orange; and thus an immense variety of colours may be produced by topical colours alone.

Adjective
colours.

It is found that adjective colours, when first mixed with their mordants, and when applied to cotton, have very little durability compared to that obtained by the method of first applying the mordant thoroughly, and then the colour. This difference holds good in the general, as well as in topical dyeing of cotton and linen, with all adjective colours, although with regard to wool it appears to be often a matter of indifference, as to the permanency of the colour, whether the mordant and the dye are applied separately or are united. But as this is not the case with cotton it still remains a great object in calico-printing to discover some method of pencilling adjective colours so as to be sufficiently durable. It is also an additional difficulty in this process that the pencilled colours always require a very full body of colour, being generally applied as finishing touches to the pattern which constitutes a very large portion of it.

In addition to the methods of calico-printing above described are those of printing by discharges and resists, which we have before alluded to. When a ground is required to be left white, it is done in the method above described, by leaving those parts untouched by the mordant, so that, when subsequently washed, the dye will be removed on the untouched parts. This plan is, however, obviously inadmissible when the general dye is given by a substantive colour, such as indigo. In such cases, therefore, some kind of covering must be applied to the white pattern parts to protect them from the dye, and to prevent it from penetrating and having some Chemical action upon it, which will destroy its permanency. In the East Indies, wax is often employed for this purpose, and in this Country a mixture of pipe-clay and paste was formerly used. The action of both of these substances is that of preventing the penetration of the colour, but a very common resist now employed is a mixture of sulphate of copper, verdigrise, alum, and gum arabic, thickened with a little pipe-clay, which is printed on the goods exactly like a mordant; this is generally used in dyeing with indigo, and acts by restoring to the indigo the oxygen which it had been deprived of by the sulphate of iron; the oxygenated indigo by this means loses its solubility, and cannot fix itself upon the cloth.

Printing by
resists.

Printing by discharge consists in applying upon the

Printing by
discharge.

Manufac-
tures.

parts of the cloth required to be white some substance which will render the dye fugitive, so that, by the ordinary means of washing, &c., it may be removed. It may be effected in two ways; either by applying some substance on the mordant, previously to the cloth being dyed, which neutralizes or destroys the effect of the mordant at that part, by rendering the colour permanent, or by applying a substance to the cloth after being dyed, which, by a Chemical action upon the colouring matter, destroys its permanency. Another branch of this part of the Art consists in applying to the cloth, previously impregnated with the mordants and dyes, substances which, themselves serving as mordants, modify or destroy the shade which the colouring matter has given, and at the same time receive a colour quite distinct from that on the rest of the cloth.

Mr. Thomson's first
patent.

(776.) These processes had been attempted for many years, both in this Country and on the Continent, but it appears that the first person who succeeded in rendering them practically useful was James Thomson, Esq., F. R. S., of Primrose Hill, who took patents for his inventions in the years 1813 and 1815. The first patent was for a method of discharging the colour from cotton dyed with Adrianople red, which process was as follows:

He mixed with one gallon of good vinegar or rectified pyroligneous acid sufficient starch and flour to render it of the consistency of the mordants commonly used by calico-printers. While boiling hot, 5 pounds of crystallized citric acid are added, and the whole well incorporated by mixing. This paste is printed or otherwise applied to parts of the cloth previously dyed Adrianople red, which were required to be white.

He then prepared a solution of oxymuriate of lime by having dissolved the dry oxymuriate of lime in water, or by passing the oxymuriatic gas into a vessel where he kept a quantity of quick lime suspended by agitation, and thus obtained an oxymuriate of lime with an excess of lime. When the paste on the cloths was dry, the latter were hooked on a frame, such as is used in dyeing indigo or China blues, commonly called a dipping frame, taking care that they were disposed in such a manner that no two folds could touch each other. He plunged this frame with the cloth so attached into a vessel containing the solution of oxymuriate of lime, keeping it gently in motion during the time of immersion, which was generally between 5 and 10 minutes, after which it was withdrawn and rinsed in cold water. The cloths were then freed of the remains of the different substances employed by the ordinary means of washing and branning, and if any of the parts of the cloth intended to be white still retained any colours, they might be cleaned by the usual process of exposure to the air, or by passing the cloth through hot water, to which is added a solution of the oxymuriate of lime. Upon the parts thus rendered white any other colours that are required may be added by the ordinary means of calico-printing.

Mr. Thomson's second
patent.

Mr. Thomson's second patent was for a method of discharging the dye from cloths dyed of any colour by substances which served as mordants in producing other colours. As this invention has proved one of the most important improvements in calico-printing which has been produced for some years, we conceive it may be interesting to the reader to have the description of the invention in the words of the Author, and we have accordingly given the specification of the patent at full length.

"The ordinary practice of calico-printing is to apply,

with the block or pencil, what are termed after-colours to certain spaces, originally left in their patterns, and intended to receive the said after-colours; or to certain spaces on the cloth, from which parts of the original pattern have been discharged, in order to admit, by a subsequent operation, the application of the said after-colours. Now, the object of my invention is by one application of the block, cylinder, roller, plate, pencil, or other mode, to remove parts of the original pattern or colour from the cloth, and at the same time to deposit a metallic oxide, or earthy base, which shall of itself be a colour, or shall serve as a mordant to some colour to be produced, as hereinafter described."

"*First.* Mix or combine with the acid called oxymuriatic acid (or dephlogisticated acid of sea salt) and water the alkaline salts of potash and soda, or, which is still better, calcareous earth or quick lime, in such proportion as will weaken or suspend the power of the said acid, so that it shall not, in such mixed or combined state, of itself and without any further operation, be able to remove or materially to improve the colours within the moderate space of time taken up in the performance of the process.

"*Secondly.* Print, stamp, pencil, or otherwise apply to those parts of the cloth, which are intended to be deprived of one colour and to receive another, a solution of some earthy or metallic salt; the acid of which, having a greater affinity or attraction for the alkaline salt or earth, with which the muriatic acid is mixed or combined, than that acid itself possesses, will disengage it, and the metallic or earthy base of which, being decomposed in the cloth, will either of itself be a colour, or serve as a mordant to some other colour to be produced as hereinafter described.

"*Thirdly.* After the metallic or earthy solution has been printed, stamped, pencilled, or otherwise applied to the cloth, as before directed, and is sufficiently dry, immerse the cloth in a solution of oxymuriatic acid combined with the alkaline salt of potash or soda, or, which I greatly prefer, with calcareous earth or lime, when the acid of the metallic or earthy solution which has been applied to parts of the cloth will immediately seize upon and combine with the alkaline salt or earth with which the oxymuriatic acid has been mixed or combined, and disengage that acid, which will almost instantly deprive of their colour those parts of the cloth to which the said earthy or metallic salt has been applied.

"*Fourthly.* Wash or otherwise remove the said acids or salts by the usual processes, and, when the earthy or metallic base deposited in the cloth is intended to receive another colour, proceed to raise it by the usual operations of dyeing, as will be further illustrated by the examples hereafter given of particular applications of the invention. The earthy solutions which I apply to those parts intended to be deprived of their colour, and to receive another, are the solutions of alumina, or earth of alum, in acids; such, for example, as the sulphate of alumina or common alum, the acetate of alumina, or nitrate or muriate of alumina. The metallic solutions which I employ are the sulphate of iron or copperas: the nitrate, muriate, or acetate of iron, the muriate or nitro-muriate of tin; the sulphate of copper or blue vitriol, or the nitrate, muriate, or acetate of copper. All acids that form soluble compounds with the before-named metals, or the earth of alum, may be employed, but those only which form the most soluble compounds, such, for example, as those enumerated above, can be

Mechanical
Processes.

Manufactures.

employed with advantage. For the more full and complete understanding of the principle laid down in the preceding part of the specification, I subjoin the following practical illustration of its application to various kinds of work. If I desire to have a yellow figure or stripe on a cloth, upon which a maddered ground has been printed; after having by the ordinary processes of calico-printing produced the red ground, or pattern, I first print, stamp, pencil, or otherwise apply to those parts intended to be yellow, a strong aluminous mordant, composed of 3 pounds of sugar of lead, 6 pounds of alum, dissolved in a gallon of water, and thickened with a due proportion of calcined starch, in the manner usually practised by calico-printers.

"*Secondly.* I prepare a solution of oxymuriate of lime, either by dissolving the dry oxymuriate of lime (commonly called bleaching powder or bleaching salts) in water, or by passing the oxymuriatic gas into a vat, vessel, or cistern, in which, by agitation or otherwise, I keep suspended such quantity of quick lime as will more than fully saturate the oxymuriatic gas. In either way I obtain a solution of oxymuriate of lime, with an excess of lime. That which I use and prefer is of the specific gravity 1050, and I seldom employ it lower than 1030 (water being considered as 1000.) The vat, vessel, or cistern, which contains the solution of oxymuriate of lime, in which I immerse the cloth, may be of any size or form best adapted to the purpose or situation. I use and prefer vessels of stone of from 6 to 8 feet deep, 6 to 7 feet long, 3½ or 4 feet broad; but larger or smaller vessels will answer very well.

"*Thirdly.* When the cloth is ready for immersion, which it is as soon as the paste is dry, I hoop it on a frame such as is used in dyeing indigo or China blues, commonly called a dipping frame, on which the cloth should be so disposed that no two folds can touch each other together. I then plunge the frame, with the cloth attached, into the vat containing the solution of oxymuriate of lime, and keep it gently in motion during the time of immersion, which rarely need exceed five minutes. The object being to remove the red dye from certain parts or places, as soon as that is done the cloth should be withdrawn from the solution of oxymuriate of lime, and plunged into or rinsed in cold water. I practise and approve the aforesaid plan of immersion, but any other plan or plans, by which the cloth can be exposed a greater or less time to the action of the oxymuriate of lime, without bringing any part of the said cloth into contact with another part, will answer very well.

"*Lastly.* After having, as before described, rinsed or washed the cloth in clean water, I free it from all superfluous remains of the different substances employed by the ordinary means of washing, dunging, and cleaning, as practised by calico-printers, after which I dye the cloth, and raise the yellow in the usual way with quercitron bark or any other yellow dye.

"If, instead of yellow, it is proposed to have a buff pattern or figure, I add to the aluminous mordant, prepared and thickened as above, one-fourth, or one-sixth, or some intermediate proportion of a solution of nitrate of iron, and proceed to print and immerse in oxymuriate of lime, as in the former case.

"The red dye will be removed as before, and its place occupied by a buff. If the buff be raised in quercitron bark, an olive will be obtained. By printing at separate times, and on different parts of the cloth, each of the above-mentioned mordants, both yellow and olive

figures, on a red ground, may be obtained. Similar effects, with trifling variations, take place when, instead of red grounds, purple or chocolate grounds are employed, but it must be observed that these colours, being produced from mordants, consist, wholly or in part, of solutions of iron, and the oxide of that metal not being removable by the process detailed in the specification, the after-colours put on will be modified more or less by the said oxide of iron. The foregoing examples are given for the more full explanation of the said invention, and the manner in which it is to be performed; but the invention, whereof I claim the sole and exclusive use, consists of printing, stamping, pencilling, or otherwise applying to cloth, previously printed and dyed, Turkey red or any other colour, any of the earthy or metallic solutions, as above directed, and immersing the whole cloth in such mixture or combination of oxymuriatic acid with water, with some of the alkaline salts or earths, as is herein directed for that purpose, so as to remove the colour or pattern from the part so printed, stamped, pencilled, or receiving such application, and, by the same process, fix on such parts either a new colour, or a mordant for a new colour."

(777.) Having thus given a general outline of the different styles of calico-printing, we purpose, as far as our limits will permit, to describe the mordants and dyeing substances made use of in producing the principal colours.

First. Printing by the application of mordants to the parts of the cloth required to be coloured.

Black colours.—The mordant employed for this colour is acetate of iron, commonly called iron liquor, produced by dissolving iron in vinegar. Some calico-printers employ copperas, and some other substances mixed with it. M. Vitalis gives the following receipts:

1st. Dissolve 4 ounces of copperas in 12 pints of iron liquor, and, after having decanted the clear part, add 4 pounds of starch, and heat the mixture in a boiler, taking care to stir continually, until the starch is well boiled.

2d. Mix 2½ pounds of superfine wheat-flour in 8 pounds of iron liquor. It must be mixed very gradually, adding a portion of the liquor at a time, and left to rest for 12 or 24 hours. It is then to be boiled for about half an hour, until the mixture has acquired the consistency of a paste, and then removed from the fire until it becomes cold.

The dye which gives the best black with these mordants is logwood and madder. Sumach and some other dyes will also produce a black, but by no means equal in beauty and intensity. Purple is given by the same mordant diluted with water.

Red.—The mordant commonly used is composed of a solution of 3 pounds of alum in a gallon of water, one-half of which is decomposed by the acetate of lime or lead. M. Vitalis gives the following:

150 pounds of pure alum is to be boiled with 3 pounds of ground Brazil wood, which must be stirred until the alum is dissolved, and 50 pounds of acetate of lead added. When the liquor begins to clarify, 6 pounds of the potash of commerce and 6 pounds of chalk are added, and the whole left for an hour to settle.

For strong reds the above mordant is thickened with starch, and, if lighter reds are required, it is thickened with gum, which must be varied in quantity according to the strength of the red required.

The dyes employed for reds are madder and sumach.

Mechanical Processes.

Manufac-
tures.

Prussian Blue.—The same mordant is used as for black, with a dye of prussiate of potash, in which the prussic acid has been set free by means of sulphuric acid.

Yellow.—Mordant used is the same as for red. The piece when slightly dunged is dyed for about one hour with one pound of quercitron bark, the infusion being gradually heated during that time from 130° to 160°.

Drab.—Mordant, dilute acetate of iron, and thickened with gum. Dye, quercitron bark.

Olive.—Mordant of the fast red mordant, with acetate of iron. Dye, quercitron bark.

Coffee Colour.—Mordant, 2 pints of the second red mordant with 2 pints of acetate of iron liquor. Dye, madder.

Puce or Carmelite Colour.—Mordant, 3 pints of the second red mordant with $\frac{1}{2}$ pint of acetate of iron liquor. Dye, madder.

Deep Brown.—Mordant, 3 pints of the second red mordant with $\frac{1}{2}$ pint of iron liquor. Dye, madder.

Violets.—Mordant, 16 parts of iron liquor with 8 pints of water and 4 ounces of Roman vitriol. The mixture to be thickened with powdered gum in the proportion of a pound to a pint. Dye, madder.

Maroon or Chestnut Brown.—Mordant, 2 pints of violet mordant with 1 pint of red mordant and 8 ounces of green copperas. Dye, madder.

Lilac.—Mordant, 1 pint of violet mordant with 1 pint of the mordant for light red. Dye, madder.

Topical
colours.

Printing by Topical Colours.—This method consists in applying the colour to the cloth after it is mixed with the mordant, by which a great deal of time and labour is saved, but the colours obtained by this means are much less permanent than those produced by the previous application of the mordant. These are called topical or chemical colours. They require no further process, after their application to the cloth, but that of washing in order to remove the gum or starch mixed up with the colour.

Topical Black.—A very good black may be produced by a decoction of logwood and galls thickened with flour, and when cold, nitrate of iron mixed with it. Vitalis gives the following :

1st. To 12 pints of acetate of iron add 4 ounces of Roman vitriol dissolved in water, and a quantity of the decoction of galls. Thicken with $3\frac{1}{2}$ pounds of starch, which is to be gradually worked up with a portion of the liquor. After it has boiled withdraw it from the fire and keep stirring till the liquor is cool ; it must then be strained through a sieve or linen cloth.

2d. Boil 2 pounds of logwood, 2 pounds of sumach, and 8 ounces of galls in 24 pints of water, till the liquor is reduced to half its volume. Add then a pint of the acetate of iron liquor, boil away 6 more pints, and take off the clear part of the bath. In this, dissolve 2 ounces of Roman vitriol, and 1 ounce of sal ammoniac ; after which thicken with starch and pass it through a sieve as before.

Pencil Blue.—This is the most important of the topical colours, and requires no further substance mixed with it to serve as a mordant, being obtained from indigo, which is a substantive colour. It is generally prepared in the following manner :

Boil in 10 gallons of water 7 $\frac{1}{2}$ lbs. of quick lime, and 15 lbs. of potash. Decant off the clear liquor, and separate the remainder from the lime by means of a filter. To 1 gallon of this solution add 1 pound of

sulphuret of arsenic (orpiment) and 1 pound of fine indigo, both previously ground together in a mill, with sufficient water to make a thick paste. Bring them gradually to boil, stirring carefully all the time, and then withdraw the fire. Thicken the solution with the best gum senegal, and for the pale shades of blue dilute with one or two measures of gum water.

The quantities and relative proportions of potash, orpiment, and indigo in a gallon of pencil blue, vary considerably with different calico-printers, and within certain limits it appears that the accuracy of these proportions is not of great importance. The solution when first made is a yellowish-green, and becomes gradually deeper, and at last blue, by exposure to the air. It must be preserved very carefully from the air, as, should it become blue, it contracts no union with the cloth, and is detached from it in the first operation of rinsing.

Another blue, less permanent, but more brilliant, is now very commonly preferred. It is made with Prussian blue, ground very fine, and mixed with muriatic acid to the consistency of a sirup. The mixture requires to be stirred every day for an hour, and afterwards thickened with gum water according to the shade wanted.

Reds.—The pale and more delicate shades of red are those chiefly sought after in calico-printing, as they are generally employed in giving relief to colours of a more sober cast ; and all the skill of the colour-maker is exerted in giving them brilliancy and richness of tint. They are chiefly produced from decoctions of Brazil, Nicaragua, or pearl wood, and cochineal, raised and fixed on the cloth with solutions of tin. The following is the method of preparing the colour with Brazil wood :

Boil 10 pounds of chips of Brazil wood in as much water as will cover them, draw off the decoction, pour on fresh water and boil as before, add the two liquors together, and evaporate slowly down to 1 gallon. To the decoction while warm add 4 ounces of sal ammoniac, and as much gum dragon or senegal as will thicken it for the work required. A solution of tin is prepared by dissolving 2 ounces of sal ammoniac in 1 pound of nitrous acid, of specific gravity 1.25, and adding 2 ounces of fine grain tin. The colour must be carefully decanted, and diluted with one quarter of its weight of pure water. A solution thus prepared is sufficient for 4, 6, or 8 gallons of the Brazil liquor, but the proportion is varied according to the shade required. When put upon the cloth it must be suffered to remain from eighteen to twenty-four hours ; the colour will be a pale and delicate pink. Nicaragua, or pearl wood, although not so rich in colouring matter as Brazil, yields a tint which, if possible, is more delicate and beautiful.

Scarlet colour is prepared from cochineal in the following manner : Add to one gallon of water 1 pound of cochineal ground as fine as flour, boil half an hour, and add 2 ounces of finely-pulverized gum dragon and 2 ounces of cream of tartar, and stir till the whole is dissolved. When the liquor is cool add one measure of the above solution of tin to two of the cochineal liquor, and incorporate them well by stirring.

Yellows.—These are generally prepared from French or Turkey berries or quercitron bark. This latter substance produces pale yellow or straw colour, but does not afford the deep bright orange yellow of the berries.

Berry yellow may be made by boiling two pounds of good berries slightly bruised in a gallon of water during three hours, taking care to replace from time to time the evaporated water with liquor obtained from the second

Mechanical
Processes.

Manufactures.

boiling of a former quantity of berries. When the liquor is cool add to it 8 ounces of alum, and if it is intended for the blocks thicken it with flour, and if for the pencil 2 ounces of sugar of lead should be added with the alum, and the colour thickened with gum dragon. This yellow is generally passed through lime water as the first operation of rinsing, by which means the greater part of the earth of the alum, which would otherwise have been carried off in the operation, is precipitated on the cloth and the colour considerably heightened.

The straw or lemon yellow is made by boiling 4 pounds of quercitron bark in 8 pints of water until the decoction is reduced to half its original bulk. This must be thickened with 3 pounds of gum added gradually. A solution of tin, composed of a mixture of 3 ounces of muriatic acid, 4 ounces of nitre, and 4 ounces of pure water, with 2 ounces of grain tin, must be added, which renders the colour of a brilliant yellow. This yellow resists vegetable acids very well, and, when placed on a blue ground, forms a very fine green. By mixing with it a little of annatto bark good orange yellows will be produced.

A yellow termed rust yellow is made with acetate of iron thickened with gum for light yellows, and with starch for the deeper shades. Rust yellow, when applied on blue, gives a deep green which serves for the stems of certain flowers. A beautiful yellow is also now produced by the chromate of lead.

Green.—The colour is very commonly produced by the mixture of the topical blue and yellow, in which the yellow predominates considerably. A very fine green may also be produced by putting upon the cloth a solution of sulphate and acetate of copper, and passing it through a strong solution of potash in which some protoxide of arsenic has been dissolved.

Purple.—If the solution of tin directed for the red be mixed with six times of its bulk of a decoction of logwood, poured while hot upon four ounces of sal ammoniac, and 2½ pounds of gum senegal, a bright and lively purple will be obtained, the hue of which varies with the strength of the decoction and the proportion of the solution of tin employed. Various shades of purple may also be produced by using different proportions of the acetate of alumina instead of the solution of tin.

Orange.—The solutions of iron in vinegar strengthened by the addition of copperas will produce this colour, but the purest and brightest gold colours are obtained from copperas and sugar of lead, in the proportion of 5 pounds of the former and 1 pound of the latter to a gallon of water. When thickened with gum and employed undiluted it affords, when limed, a full strong gold colour, and with two, four, six, &c. times its bulk of water, various shades of orange and buff, which resist the action of the air, alkalis, and soap, and are rather exalted and improved by frequent washing.

A beautiful but fugitive orange may also be obtained by boiling ½ a pound of annatto with 1 pound of caustic potash in a gallon of water, and thickening the liquor with gum. This colour, however, acts very powerfully on the sieves and blocks, which it soon destroys, and on this account, and also from its want of permanency, is seldom used.

Violets.—These are variously compounded according to the colour required.

1st. By mixing chemical black in various proportions with berry or bark yellow. The depth and fulness of the colour depend on the quantity of black.

2d. By a decoction of logwood added in a greater or less proportion to the bark or berry yellow.

3d. By the addition of copperas or nitrate of iron to decoctions of yellow or astringent colouring matters, such as bark, sumach, weld, &c., each of these produces a different hue, varying from a green colour to a drab or cloth colour. By mixing these decoctions in different proportions, and by varying their strength, and the quantities of copperas or nitrate of iron added to each, a multiplicity of shades may be produced, of which it is impossible to convey any precise or definite idea.

We have now explained the methods usually employed of producing the principal colours, both by the previous application of the mordant, and by the addition of the mordant previous to the application of the colour.

In the practice of calico-printing these two modes of colouring are very frequently combined in the same piece when a number of different colours are required.

(778.) The reader will form a good idea of the mode of managing different styles of calico-printing from the following example given by Vitalis.

Calicoes of one Block.

First example.—Violet on a white ground.

1st Operation. The impression of the violet mordant.

2d. Dyeing and washing.

3d. Dyeing in a madder bath.

4th. Branning and exposure on the grass to clear the grounds.

Second example.—Black on a yellow ground.

1st Operation. Bath of yellow mordant.

2d. Dyeing in a weld bath.

3d. Impression of topical black.

Calicoes of two Blocks.

First example.—Two olives on a white ground.

1st Operation. Impression of the first olive mordant.

2d. Impression of the second olive mordant.

3d. Dyeing in a weld bath.

Second example.—Red and blue on a white ground.

1st Operation. Impression of the red mordant.

2d. Dyeing in a madder bath.

3d. Impression of topical blue.

Third example.—Yellow and black on a white ground.

1st Operation. Impression of the yellow mordant.

2d. Dyeing in a weld bath.

3d. Impression of the topical black.

Calicoes of three Blocks.

Example.—Two olives and a yellow on a white ground.

1st Operation. Impression of the first olive mordant.

2d. Impression of the second olive mordant.

3d. Impression of the yellow mordant.

4th. Dyeing in a weld bath.

The third block might also be performed by the impression of the topical yellow.

Calicoes of four Blocks.

Example.—Black, red, violet, and yellow, on a white ground.

1st Operation. Impression of the black mordant.

2d. Impression of the red mordant.

3d. Impression of the violet mordant.

4th. Dyeing in a madder bath.

5th. Impression of the yellow mordant.

6th. Dyeing in a weld bath.

Mechanical Processes.

Printing calicoes with one block, and with two or more blocks.

Manufac-
tures.

The last colour might have been given equally well by a topical yellow.

Calicoes of five Blocks.

Example.—Black, red, violet, yellow, and blue, on a white ground.

- 1st Operation. Impression of the black mordant
- 2d. Impression of the red mordant.
- 3d. Impression of the violet mordant.
- 4th. Dyeing in a madder bath.
- 5th. Impression of the topical blue.
- 6th. Impression of the topical yellow.

Calicoes of six Blocks.

Example.—Two olives, black, two reds, and yellow, on a white ground.

- 1st Operation. Impression of the black mordant.
- 2d. Impression of the first red mordant.
- 3d. Impression of the second red mordant.
- 4th. Dyeing in a madder bath.
- 5th. Impression of the first olive mordant.
- 6th. Impression of the second olive mordant.
- 7th. Impression of the yellow mordant.
- 8th. Dyeing in a weld bath.

In all the examples above given the cloth must be finally branned and exposed in the fields to clear the grounds. When topical colours are employed this process must be performed previously to their application. The impression of the first mordant is now generally given by the padding Machine, and the mordant of that colour is chosen which is most prevalent in the pattern; sometimes the first two mordants are given by this Machine, but beyond that number they must be performed by blocks. The greater part of the common calicoes, which contain only one or two colours, can be done entirely without the use of blocks, and thus a great deal of labour is saved, and the price of the article, consequently, greatly reduced. When a great number of colours are given, the quantity of labour is greatly increased, and the price of the articles bears no proportion to that of the simple patterns. A great number of colours may be given to cotton goods at a little expense by the topical colours, but they will not stand washing, and are, consequently, much less valuable for all the ordinary purposes.

Printing by Resisting Pastes.

Printing by
resists

(779.) The resists are generally used in blue-dipping; they are printed on the goods like the mordants, and four-and-twenty hours after the impression the goods are passed through the dyeing-vat, and after washing, the parts where the paste has been applied become white. Vitalis gives the following receipt for resists:

"Dissolve in 2 litres (a little above a quart) of water 4 ounces of sulphate of copper, and 6 ounces of verdigrise, to which add 1 pound of gum arabic, and when it is dissolved pass through a fine sieve, and let it set and decant. The bath is thickened by a pound of pipeclay, well ground, sifted, and kneaded, with 3 or 4 ounces of water. It must be mixed very carefully in the bath, and well triturated before being made use of."

Action of
the resist.

The oxide of copper, which forms the basis of the resist, restores to the indigo the oxygen which it has been deprived of by the sulphate of iron. The oxygenated indigo loses its solubility, and consequently

cannot fix itself on the stuff. Since the resist intended to nullify the action of the indigo acts merely by the oxide of copper which it contains, it follows that the proportions of the oxides are not indifferent, and that the measure will not perfectly accomplish its end, unless the dose of oxide of copper, which the sulphate can furnish, be adequate to neutralize the action of the indigo. A similar result will ensue if the resist be not suitably thickened. The proportions of cupreous salts ought to be as little as can be to effect the purpose, as if their quantity be too great their operation would be extended to the indigo diffused throughout the bath.

The following examples will illustrate the manner of managing this style of printing:

To make a Sky-blue on a Dark Blue.

- 1st Operation. Dye the cloth in a sky-blue vat.
- 2d. Apply the resist on the parts intended to be sky-blue.
- 3d. Dye the cloth in a dark blue vat.
- 4th. Immerse it in a bath acidulated with the oil of vitrol, or muriatic acid, in order to carry off the particles of lime suspended in the vat.

Sky-blue, Dark Blue, and White.

- 1st Operation. Apply the resist to the parts intended to be white.
- 2d. Dye the cloth in a sky-blue vat.
- 3d. Apply the resist on the parts intended to be sky-blue.
- 4th. Dye the cloth in a dark blue vat.
- 5th. Immerse in acidulated water.

Deep Blue, Sky-Blue, Green, Yellow, and White.

- 1st Operation. Apply the resist to the parts intended to be white and yellow.
- 2d. Dye in a light blue vat, and dry.
- 3d. Immerse in water acidulated with sulphuric acid to brighten the colour, and wash and dry.
- 4th. Apply the resist to the parts intended to be light blue and green.
- 5th. Dye in a dark blue vat, and brighten.
- 6th. Apply the red mordant on the parts intended to be yellow and green.
- 7th. Dye in a bath of weld or quercitron.

The white portions which were impressed with the mordant will become yellow, the blue parts impressed with the red mordant green, while the parts left untouched by the mordant will come out, by washing and branning, white, light blue, and dark blue.

Printing by Discharges.

(780.) Little further is required to be said on this subject, as the methods of accomplishing this branch of calico-printing have been pointed out at considerable length in the specification of Thomson's patent, given in the preceding part of the Essay. In printing with discharges on a mordant, the discharge is prepared with nitric, citric, oxalic, or tartaric acid, or bisulphate of potash thickened with roasted starch. It is necessary that the mordant previously put on the goods be made very dry by passing them over the steam cylinders; the discharge is then applied by means of the padding Machine used for mordants, and the goods well washed and exposed on the grass. This style is most frequently used for mourning garments, composed of a figure on a

Mechanical
Processes.

Printing by
discharges.

Manufactures. black ground ; but figures may, by the same process, be readily obtained on a ground of red, violet, or any other colour.

White discharge on indigo grounds.

A neat and expeditious style of discharge work on indigo grounds has of late years been extensively employed by calico-printers in this Country. A paste is made with aquafortis and pipeclay, which is applied by a cylinder of wood having the pattern cut upon it. The cloth, immediately on receiving the impression, is passed through a strong body of steam, issuing from a row of small orifices in a horizontal box. The high temperature gives blanching energy to the nitric acid, and the accompanying moisture dilutes it so as to prevent corrosion of the cotton fibres. The safety of the goods is ensured, however, by a thorough washing.

Discharges on dyed goods.

The parts rendered white by the above processes may be dyed of any colour, either by the application of a mordant, or by topical colours. When, however, the discharged part of the cloth is required to be coloured it may be accomplished with fewer processes, and much better by the methods pointed out by Mr. Thomson ; for instance, if it is required to have yellow figures on an olive ground, a discharge must be found which, in destroying the colour communicated by the iron, will at the same time change the colour to yellow. This may be effected by a solution of tin, prepared by adding a little muriatic acid to a solution of muriate of tin, and afterwards carefully thickening with starch previously boiled, to insure the thorough union of the ingredients. The goods must then be immediately washed, to prevent the discharge acting too long on the colour, and the parts impressed with the mordant will be found changed to a good yellow colour.

Scarlet on a black ground.

In the same way, if calico has been dyed black in a logwood-bath mixed with iron liquor, if any parts be impressed with a solution of tin, the ferruginous parts touched with the discharge will be removed and will pass from a deep black to a very brilliant crimson. By subjecting to the same treatment calicoes dyed of different colours and shades, determined by different degrees of oxidation of the iron, a great variety of shades and colours will be produced.

Green on a blue ground.

A beautiful green may be produced on a blue ground by dyeing the cloths first with a pale blue in an indigo vat, passing them through a bath of sumach and sulphate of iron, and finishing in a bath of quercitron with alum. The green colour produced by the indigo

and quercitron remains masked, as well as the other Mechanical Processes. colours, by the oxide of iron in the sulphate until the solution of tin be applied, which causes the other colours to disappear, and gives to those that remain a lustre which they would not otherwise have had, because the solution of tin renders the quercitron yellow more vivid, and because from this vivid yellow associated with the blue results a more brilliant green.

Calico-printers make use of these methods, combined with that of mordants, in producing more readily some varieties of colours, as will be understood from the following examples :

First example.—Olive, yellow, and white.

1st Operation. Immersion in the olive mordant.

2d. Impression of the white discharge, wash and dry.

3d. Dyeing in a weld bath.

4th. Impression of the yellow discharge, and wash.

Second example.—Bright red and dull red : white, yellow, and black, on an olive ground.

1st Operation. Impression of the red mordants.

2d. Dyeing in a madder bath.

3d. Application of reserves or resists on the reds.

4th. Immersion in the olive mordant.

5th. Impression of the white discharge.

6th. Dyeing in a weld bath.

7th. Impression on the yellow discharge.

8th. Impression of the topical black.

If, instead of applying the yellow discharge, thickened as usual with starch, one-third more starch be employed, and a colouring of decoction of Turkey berries or Brazil wood be added, there will be obtained, in the first case, a richer yellow, and, in the second, an orange-yellow.

We might enumerate many other combinations of the different styles of calico printing which are had recourse to in producing the great variety of beautiful colours which these goods present, the extent assigned for this Essay will not, however, permit us to enter at greater length on this subject ; and we beg to refer the reader for further information to Dr. Ure's Notes to his Translations of Berthollet's *Chemistry*, Parke, *Chemical Essays*, and to Vitalis on *Dyeing*.

(781.) The advance which the Art of calico printing has made within a few years will be illustrated by the following Table, in which is stated the quantities of printed and dyed cotton exported from this Country, distinguishing the various Countries to which they were imported, for each year, from 1820 to 1831, both inclusive :—

Countries to which exported.	1820.		1821.		1822.		1823.		1824.		1825.	
	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.
Russia	3,449,391	248,358	910,159	58,979	361,701	20,797	922,871	57,913	516,623	30,880	467,483	27,968
Sweden	...	...	112	15	318	28	1,000	100	...	...	26,877	1,470
Norway	248,820	14,435	266,373	14,585	178,220	9,679	426,622	21,428	282,909	13,712	282,319	14,538
Denmark	195,974	12,961	143,953	7,072	149,690	8,880	102,475	4,985	99,491	3,910	143,596	6,636
Prussia	4,519,676	175,243	1,577,994	52,142	1,900,856	53,999	536,809	18,223	266,366	9,805	169,031	6,507
Germany	32,190,496	1,970,720	25,022,981	1,453,140	24,779,359	1,412,625	20,138,397	1,159,857	21,509,251	1,104,559	23,083,895	1,127,112
United Netherlands	8,412,235	560,665	7,953,062	537,910	9,323,613	582,545	10,957,215	582,955	7,665,959	416,587	8,066,841	462,872
France	8,660	783	6,245	575	5,435	485	576	35	64,407	2,409	54,748	3,281
Portugal Proper, Azores, & Madeira.	7,597,933	425,374	10,492,497	529,561	11,155,591	487,137	7,174,524	324,069	9,589,200	392,652	8,009,029	329,755
Spain and Balearic Islands	...	...	...	...	...	...	490,119	20,177	599,301	37,213	800,069	43,250
Canaries	1,399,300	86,799	1,137,972	49,697	948,993	42,423	248,144	12,786	431,077	15,728	244,753	11,053
Gibraltar	7,849,076	471,034	7,012,146	396,267	12,564,351	668,889	8,841,514	399,733	10,359,280	545,494	7,536,984	308,967
Italy and the Italian Islands	11,121,373	637,793	7,933,581	434,346	15,277,443	819,829	11,077,518	536,349	13,561,996	616,623	9,927,865	438,920
Malta	1,194,989	61,132	857,336	39,228	992,071	43,647	1,648,189	71,546	704,001	33,838	732,229	32,042
Ionian Islands	25,053	1,319	1,589	533	15,893	468	...	...	...	...	5,746	354
Turkey	3,945,332	206,458	3,033,472	162,537	4,515,387	191,353	5,447,353	234,027	6,831,320	285,637	5,166,623	229,471
Egypt (Ports on the Mediterranean)	...	...	...	...	...	...	...	...	14,833	487	29,765	873
Tripoli, Barbary, and Morocco	315,156	18,633	594,793	37,625	837,473	46,904	586,072	28,530	504,254	25,112	808,948	39,733
Western Coast of Africa	601,203	35,472	829,805	42,934	564,173	19,673	1,453,765	60,780	665,489	31,808	560,474	26,144
Cape of Good Hope	...	...	...	...	...	...	...	...	...	...	...	...
Carried over	83,974,667	4,927,179	67,774,070	3,817,166	84,270,567	4,409,361	70,088,975	3,534,956	73,758,757	3,567,454	66,117,284	3,110,940

Countries to which exported.	1820.		1821.		1822.		1823.		1824.		1825.	
	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.
Brought forward....	83,074,667	£. 4,927,179	67,774,070	£. 3,817,166	84,270,567	£. 4,409,361	70,088,975	£. 3,534,956	73,758,757	£. 3,567,454	66,117,284	£. 3,110,946
Cape Verd Islands.....	...	...	...	...	...	...	...	...	...	...	...	...
Saint Helena.....	...	...	...	...	...	...	...	...	...	...	...	...
Mauritius.....	...	...	...	...	...	...	...	...	...	...	...	...
East India Company's Territo- ries and Ceylon.....	...	...	...	...	...	...	...	...	...	...	...	...
China.....	7,467,146	474,004	9,976,878	589,158	9,029,204	486,645	...	...	...	...	...	...
Sumatra, Java, and other Islands of the Indian Sea.....	...	...	...	...	...	...	2,955,233	141,360	1,747,716	103,648	1,646,895	64,811
New South Wales and Van Die- men's land.....	83,715	5,670	113,716	6,987	214,117	12,048	129,838	7,278	254,443	10,987	326,835	15,908
Philippine Islands.....	...	...	...	...	...	...	...	...	245,588	17,411	...	...
British North American Colonies...	1,804,756	99,344	6,109,725	80,856	2,526,000	114,213	3,001,271	134,948	3,429,143	146,378	3,819,478	174,238
British West Indies.....	12,920,630	716,062	19,078,372	850,894	12,681,598	512,007	15,487,812	616,049	17,047,979	669,621	18,768,440	818,783
Haiti.....	...	...	...	...	...	...	2,652,504	119,518	3,481,506	145,951	3,989,720	171,912
Cuba, and other Foreign West Indies.....	5,355,387	260,246	9,241,501	395,060	7,440,832	327,007	6,390,116	270,937	6,514,597	258,990	4,538,105	197,315
United States of America.....	12,770,687	622,221	20,676,819	987,312	21,612,760	957,328	22,046,801	951,926	26,171,669	1,162,617	33,549,124	1,517,770
Mexico.....	...	...	...	...	...	...	1,956,627	100,128	2,674,373	145,974	4,272,696	244,650
Guatemala.....	3,512,676	215,940	4,157,575	233,145	6,662,766	345,411	...	...	...	...	...	...
Columbia.....	...	...	...	...	...	...	1,397,403	54,310	1,604,191	81,863	3,477,006	171,210
Brazil.....	7,477,006	401,599	9,097,354	470,853	6,385,115	301,734	11,971,818	536,818	16,738,678	696,131	20,029,116	821,493
States of the Rio de la Plata.....	...	...	...	...	...	...	2,057,029	106,032	6,452,181	300,984	4,176,089	201,697
Chili.....	...	...	...	...	...	...	1,504,498	86,665	3,722,935	166,985	2,719,250	123,836
Peru.....	...	...	...	...	...	...	1,209,952	57,731	2,795,179	141,924	3,482,518	193,166
Isles of Guernsey, Jersey, Alder- ney, Man, &c.....	220,474	20,240	248,992	22,811	176,198	14,880	187,728	10,479	293,668	21,324	334,478	26,326
Total.....	134,687,144	7,742,505	146,475,002	7,434,242	156,999,157	7,480,634	149,631,387	7,096,341	174,558,549	8,011,332	178,427,159	8,185,217

Countries to which exported.	1826.		1827.		1828.		1829.		1830.		1831.	
	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.	Yards.	Declared value.
Russia.....	927,155	50,157	1,313,873	62,876	555,584	24,470	710,753	32,993	934,407	36,874	382,326	14,795
Sweden.....	7,115	600	18,281	1,162	8,121	501	1,458	164	1,662	65	3,010	98
Norway.....	234,467	10,443	112,166	4,395	240,616	9,786	333,016	12,429	377,555	12,310	253,272	7,835
Denmark.....	71,603	2,786	37,946	1,744	46,474	2,102	45,814	2,074	57,898	1,534	36,536	977
Prussia.....	18,425	766	11,503	602	2,209	100	4,978	197	...	...	568	40
Germany.....	22,578,566	909,712	29,424,057	1,084,361	24,070,038	878,919	27,577,427	806,033	28,806,295	832,526	28,323,466	689,992
United Netherlands.....	7,118,213	330,478	7,695,551	329,206	8,231,158	329,034	7,304,421	307,700	7,034,705	280,176	7,295,180	228,827
France.....	51,495	3,219	172,726	7,599	22,496	2,776	158,238	5,372	21,415	1,135	256,720	8,991
Portugal Proper, Azores, & Madeira.	7,371,045	279,376	10,499,000	377,534	6,044,823	227,559	8,769,152	321,633	8,545,697	309,401	8,824,177	284,662
Spain and the Balearic Islands.....	779,861	38,067	206,694	8,741	228,279	9,332	4,166,047	162,546	2,871,736	106,169	1,586,512	54,045
Canaries.....	66,179	3,405	312,253	13,198	310,161	11,458	287,329	10,494	311,821	10,867	242,258	6,911
Gibraltar.....	6,379,692	277,483	7,981,075	333,344	8,744,559	364,967	3,999,731	154,089	1,750,307	66,700	3,832,398	116,034
Italy and the Italian Islands.....	9,416,981	396,583	10,183,248	397,846	11,896,545	450,081	11,816,584	462,499	17,725,256	762,333	11,072,455	397,852
Malta.....	904,334	37,795	939,122	34,046	1,097,318	37,690	651,860	24,326	409,724	16,228	435,939	18,039
Ionian Islands.....	5,843	410	48,772	1,893	64,366	2,339	45,680	1,681	63,935	2,227	87,401	2,392
Turkey.....	3,515,758	143,352	4,269,971	160,940	1,048,157	39,329	3,608,403	128,317	9,333,800	336,711	4,985,681	167,638
Morea.....	...	...	...	...	...	...	...	...	159,500	3,792	29,493	660
Egypt (Ports on the Mediterranean)	29,890	969	33,761	976	88,085	2,857	52,171	2,456	162,647	8,026	304,437	11,551
Tripoli, Barbary, and Morocco.....	...	...	333,316	11,884	4,613	176	...	...	...	...	...	...
Western Coast of Africa.....	504,273	22,818	854,769	35,880	1,309,633	50,318	1,647,570	61,217	1,889,946	74,545	1,645,462	56,788
Cape of Good Hope.....	333,106	14,025	828,992	31,433	1,122,181	43,424	1,382,932	44,156	1,566,132	55,011	944,162	34,297
Cape Verd Islands.....	...	...	...	...	12,388	454	...	...	...	...	...	...
Saint Helena.....	27,662	1,127	22,135	812	18,182	777	14,666	583	14,758	593	36,605	1,149
Mauritius.....	147,866	6,665	...	...	623,385	26,973	461,057	17,098	591,497	18,447	402,961	14,364
East India Company's Territo- ries and Ceylon.....	8,993,001	381,291	628,126	26,729	10,498,666	424,623	9,400,125	354,997	...	...	...	...
China.....	...	...	12,668,425	526,285	...	...	...	...	11,393,231	456,052	12,285,037	395,086
Sumatra, Java, and other Islands of the Indian Sea.....	631,374	30,538	294,340	12,757	1,349,665	52,544	1,305,332	56,060	911,331	42,421	2,109,444	88,720
Philippine Islands.....	359,888	16,022	851,971	39,096	...	...	34,563	1,909	779,571	31,020	432,988	15,054
New South Wales and Van Die- men's Land.....	522,516	24,676	50,973	3,115	448,154	18,854	165,891	7,863	427,265	16,131	886,507	31,836
British North American Colonies...	3,175,163	127,152	3,858,756	138,336	4,901,733	178,787	4,771,859	161,322	5,670,578	195,068	7,803,489	299,499
British West Indies.....	11,741,565	457,136	15,053,772	529,415	11,695,544	406,583	17,686,657	582,702	11,210,627	376,125	10,804,365	322,576
Haiti.....	1,474,941	56,165	2,661,638	97,413	2,865,314	104,143	3,683,052	129,095	4,568,219	131,206	3,851,470	97,035
Cuba, and other Foreign West Indies.....	3,022,893	117,149	6,131,910	227,046	5,335,053	199,121	6,906,986	243,578	5,778,782	215,284	6,945,058	225,568
United States of America.....	21,446,139	934,445	35,330,320	1,570,335	25,840,720	1,207,544	24,143,240	1,831,719	33,899,163	1,504,591	37,833,736	1,535,472
Mexico.....	1,555,311	76,164	5,975,406	277,682	2,894,234	140,611	2,654,206	105,264	8,237,012	333,241	6,176,611	262,348
Columbia and Guatemala.....	1,514,693	63,876	2,396,469	83,536	2,188,432	78,399	1,938,958	72,422	2,003,150	82,277	2,258,204	80,396
Brazil.....	10,367,822	398,786	15,879,947	539,334	29,942,569	1,099,543	19,446,551	710,656	18,069,393	667,696	7,845,503	246,026
States of the Rio de la Plata.....	1,412,723	63,446	682,402	31,975	2,269,222	90,016	5,561,159	244,350	4,783,178	176,841	2,190,920	71,977
Chili.....	1,273,659	54,168	1,693,323	74,218	5,401,265	226,031	7,099,014	298,438	5,079,190	211,716	6,062,084	238,408
Peru.....	564,594	29,696	1,245,765	56,728	1,918,997	90,794	1,758,752	85,713	3,752,309	156,260	3,270,594	120,936
Islands of Guernsey, Jersey, Al- derney, and Man.....	451,246	27,646	372,461	29,352	484,620	25,335	415,410	25,218	583,742	25,675	453,846	19,056
New Zealand and South Sea Islands	...	...	469,403	20,635	28,925	1,107	1,810	70	3,037	90	3,157	105
Total.....	128,897,111	5,388,592	181,544,618	7,184,459	173,852,475	6,859,447	180,012,152	6,662,623	199,799,466	7,557,373	182,194,032	6,098,035

Tanning.

Tanning.

(782.) Tanning is the Art of impregnating the hides of animals with a substance termed *tannin*, usually obtained from oak bark, which, by a peculiar Chemical action it exerts on the gelatinous part of the skins, renders them impervious to water and not liable to decomposition.

It is difficult to say at what period the Art of tanning

was discovered, for something of the kind must have been practised at a very early period, as the skins of beasts which certainly formed the first covering of Man would, without some such process, have become putrid and useless; and it, accordingly, appears that the Ancients possessed the tanning Art in some degree of per-
fection.

Manufactures.

The astringent matter which converts the skin into leather abounds in so many vegetables in every Country, that accident would soon lead to some method of producing the change. Independently, however, of vegetables, many mineral substances have the property of rendering the skins incorruptible to a certain extent, and some mineral waters containing copper or iron will produce the same effect. Hence we may conclude that some means of giving preservation to the skins of animals must have been known at a very early period.

Of late years considerable changes have taken place in the modes of tanning, so that this operation, which a few years ago took several months to complete, can now be done in as many days. The time thus saved is, of course, of great importance to the tanner, as it enables him to sell the manufactured article at a lower price. The leather, however, made by this hastened process is considered to be less perfect than by the old method, an opinion which is supported by many eminent tanners and scientific men, among whom may be mentioned Sir Humphrey Davy, who devoted a great deal of time to the investigation of this subject. Parts of the hide which are hard have not time to become perfectly saturated with the tanning liquor, so that an irregularity in the quality of the leather is produced; for which reason a great number of tanners still continue the old system, and this advantage allows them, in some measure, to compete with those who employ the quicker process.

Theoretical remarks on tanning.

Theory of tanning.—Before entering into a description of the manual operations of tanning, we propose to make a few remarks on the Chemical nature of the process, a subject which has engaged the attention of some of the most eminent Chemists, among whom Seguin was the first who ascertained the peculiar vegetable matter which is essential to this process, and which is possessed of the characteristic property of precipitating gelatine from its solutions. Mr. Proust has since investigated many other properties of this substance, but neither these nor any other Chemists have yet carried their investigations so far as to determine the various affinities of tannin, and especially how its action upon vegetable matters is modified by combination with other substances. This task was reserved for Sir Humphrey Davy, who bestowed, for an interval of two years, the chief part of his leisure time on a course of experiments on this subject, which he laid before the Royal Society, who published the results in their Transactions for the year 1803. As the Paper contains a great deal of matter both serviceable to the practical tanner, as well as interesting to the scientific Chemist, we avail ourselves of the abstract published by the Society, which elucidates the principal facts in a very complete and concise manner.

Sir Humphrey Davy's experiments.

(783.) The Paper consists of five parts, the titles of which are as follows:—1. Observations on the Analysis of Astringent Vegetable Infusions. 2. Experiments on the Infusion of Galls. 3. Experiments on Catechu. 4. Experiments and Observations on the Astringent Infusion of Barks, and other Vegetable Productions; and, 5. General Observations.

Analysis of vegetable infusions.

1. *As to the analysis of vegetable infusions.*—The substances which have been supposed to exist most generally in them are tannin, gallic acid, and extractive matter. The presence of tannin in an infusion is known by the precipitate it forms with gelatine, such as glue or isinglass; but the process requires many and very delicate precautions. Previously to the experiments the in-

fusions are materially affected by exposure to the atmosphere: the tanning principle in different vegetables demands for its saturation different proportions of gelatine, and the quantity of precipitate obtained by filtration is not always proportionate to the quantity of tannin and gelatine in the solution, but is materially influenced by the degree of their concentration. Hence it follows, that the solutions of gelatine for the analysis should be employed in as high a state of saturation as is compatible with their perfect fluidity. They should be used only when quite fresh, and, as their relative effects were found to be influenced by their temperature, it was found expedient to bring them, and the infusions on which they were designed to act, as nearly as possible to a common degree of temperature: great care must also be taken to prevent any excess of gelatine.

Duly attending to all these precautions the general result is, that in any given case where the quantity of gelatine in the solution employed upon an astringent infusion is compared with the quantity of precipitate obtained, the difference between them may be considered as the proportion of tannin contained in the infusion.

The tannin being thus separated, it remains to ascertain the proportion of the two other ingredients in the infusion by gallic acid and the extractive matter. The first step here was slow evaporation, by which the latter substance is in part rendered insoluble so as to subside at the bottom of the vessel. A proportionate quantity of alcohol being next poured upon the fluid, thus reduced to a thick consistency, both the gallic acid and the soluble extractive matter, if there were any remaining in the infusion, was dissolved. The great difficulty now was to separate the gallic acid and the extractive matter. Ether and alumina were tried without the desired effect, the affinities of these two agents with those substances not being sufficiently distinct to produce the separation. Some judgment may, however, be formed by means of the salts of alumina and the oxygenated salts of iron. Muriate of alumina precipitates much of the extractive matter from the solutions without acting materially upon the gallic acid; and after this precipitation some idea may be formed concerning the quantity of gallic acid by the colour it gives with the oxygenated sulphate of iron.

2. *Concerning the infusion of galls.*—The strongest solution of galls was obtained by repeatedly pouring distilled water upon the best Aleppo galls broken into small pieces; it was of the specific gravity 1.068°; 400 grains of the solution produced by evaporation, 53 grains of solid matter, which, as well as could be estimated by the methods of analysis described in the preceding section, consisted of about $\frac{9}{10}$ of gallic acid united to a minute portion of extractive matter. One hundred grains, moreover, of this solid matter left, after incineration, nearly $4\frac{1}{2}$ grains of ashes, which were a mixture of lime with carbonate of lime and a small portion of fixed alkali.

Infusion of galls.

Here follows a long series of experiments on the infusion of gall-nuts, in which it was exposed to or combined with all manner of chemical agents, viz. sulphuric, muriatic, and nitric acids, potash, soda, ammonia, and a variety of alkaline earths, magnesia, alumina, different solutions of neutral salts, metallic oxides, and other substances, the list of which is too long to be here inserted. Many of the results may be considered as insulated facts, but those who attend to inquiries of this nature will find most of them connected with useful

Manufac-
tures.

conclusions, tending to elucidate this obscure, but, no doubt, very interesting part of Chemistry. The ultimate result of these experiments, as to the constituent parts of gall-nuts, is that 500 grains of good Aleppo nuts gave, by lixiviation with pure water, till all the soluble parts were taken up, 185 grains of solid matter, and that this matter, examined by analysis, consisted of

	Grs.
Tannin.....	130
Gallic acid with a little extractive matter	35
Mucilage and matter rendered soluble by evaporation	12
Calcareous earth and saline matter.....	8
	—
	185

A piece of dry calf-skin, perfectly free from extraneous matter, that weighed 180 grains after being prepared for tanning by long immersion in water, was tanned in a portion of the infusion being exposed to it for three weeks. When dry the leather weighed 295 grains, so that, considering this experiment as accurate, leather quickly tanned, by an infusion of galls, consists of about 61 grains of skin and 39 of vegetable matter in 100 grains.

After depriving a portion of the infusion of all its tanning matter, by repeatedly exposing it to the action of pieces of skin, it was found to give a much lighter colour to oxygenated sulphate of iron than an equal portion of a similar infusion, which had been immediately precipitated by solution of isinglass, which Sir Humphrey Davy was rather inclined to attribute to the decomposition of the gallic acid by exposure to the atmosphere than to its absorption by the skin.

Extract of
catechu.

(784.) 3. *On the extracts of catechu, or terra Japonica.*—This extract is said to be obtained from the wood of a species of mimosa, which is found abundantly in India, by decoction and subsequent evaporation. There are two kinds, the one sent from Bombay and the other from Bengal, which somewhat differ from each other in their external appearance, but very little in their Chemical composition. The tastes of both are sensibly astringent, and neither of them deliquesces, or is apparently changed by exposure to air.

Sir Joseph Banks, at that time President of the Royal Society, was the first person who, noticing the more obvious qualities of this substance, suspected it contained the tanning principle, and being possessed of a quantity of it, he supplied Sir Humphrey Davy with all he wanted for the purpose of Chemical examination. The first experiments showed that its solution copiously precipitated gelatine, and that it speedily tanned skins; and hence he was encouraged to undertake the particular investigation of its properties, the account of which is the subject of the present section.

His mode of proceeding, of course, could not differ materially from that which he adopted in the analysis of the gall-nuts, and indeed most of the same, and some additional Chemical agents, have been put to the test. The ultimate analysis has been attended with some difficulty, different specimens of this substance, though to all appearance quite pure, differing materially among themselves; the natives, for the sake of profit, being apt to adulterate what they sell either with sand, earthy substances, or other extraneous matter.

Sir Humphrey Davy, in order to obviate this difficulty, selected a number of specimens, such as he had reason to think the least tainted, and, having reduced

them into powder, he found the two sorts to consist of the following ingredients:—200 grains of the extract of catechu from Bombay consisted of

	Grs.
Tannin	109
A peculiar extract matter	68
Mucilage	13
Residual matter, chiefly sand and calcareous earth	10
	—
	200

The same quantity of the extract from Bengal yields

	Grs.
Tannin	97
Peculiar extractive matter	73
Mucilage	16
Residual matter, viz. sandy, with a small quantity of calcareous and aluminous earth .	14
	—
	200

With respect to the application of this substance to tanning, Sir Humphrey Davy made the following experiments. Of two pieces of calf-skin, which weighed when dry 132 grains each, and which had been prepared for tanning, one was immersed in a large quantity of the infusion of the extract of catechu from Bengal, and the other in an equal portion of the infusion of the extract from Bombay. In less than a month both were found converted into leather, and when freed from moisture by long exposure to the sun they were weighed. The first piece had gained about 34 grains, and the second piece 35½ grains. The colour of the leather was much deeper than that tanned, and on the upper surface it was of a reddish-brown. It was not acted upon by hot or cold water, and its apparent strength was the same as that of similar leather tanned in the usual manner.

In examining the remainder of the infusions of the catechu, in which the skin had been converted into leather, he found in them much less extractive matter than might be expected from the comparative analysis of equal portions of the unaltered infusions made by solutions of gelatine. At first he was inclined to suppose that the deficiency arose from the action of the atmosphere upon the extractive matter, by which a part of it was rendered soluble. But in considering that there had been very little precipitation in the process, he was led to adopt the supposition that it had entered into union with the skin at the same time with the tannin, and this supposition was confirmed by further experiments.

(785.) 4. *On the infusion of barks and other vegetable productions.*—The experiments described in this section were chiefly made on the strongest infusions of the bark of oak, Leicester willow, and Spanish chestnut; each of them were nearly of the specific gravity of 1.05. Their tastes were alike strongly astringent. 200 grains of each, submitted to evaporation, yielded

		Grs
<i>Oak bark</i>	Quantity of tannin	14
	Solid matter.....	17
<i>Leicester willow</i> ...	Quantity of tannin.....	14½
	Solid matter	16½
<i>Spanish chestnut</i> ..	Quantity of tannin	13
	Solid matter.....	16½

These substances also gave by incineration only a very small quantity of ashes, scarcely $\frac{1}{150}$ part of their original weights; and these ashes consisted chiefly of

Mechanical
Processes.

Infusion
of barks.

Manufac-
tures.

calcareous earth and alkali, the quantity being greatest from the matter produced from the chestnut bark.

These several infusions were acted upon by the acids and pure alkalis in a manner very similar to that adopted with the infusion of galls. No gallic acid whatever could be obtained from any of them, and, if any be contained, it must be in a state of intimate combination with extractive matter. The proportions of the astringent principle in barks vary considerably according to the age and size of the trees from which they are taken, and probably also according to the different seasons in which they are gathered. In every astringent bark the interior white part (that is, the part next to the wood) contains the largest quantity of tannin; the proportion of extractive matter is generally greatest in the middle and coloured part, but the epidermis seldom furnishes either tannin or extractive matter.

Two pieces of calf-skin, which weighed when dry 120 grains each, were tanned, one in the strongest infusion of Leicester willow bark, and the other in the strongest infusion of oak bark. The process was completed in both instances in less than a fortnight, when the weight of leather formed by the willow bark was found equal to 161 grains, and that by the oak bark to 164 grains.

In another experiment, two pieces, which weighed when dry 94 grains, were slowly tanned, one by the weak infusion of the willow, and the other in oak bark. The process was completed in about three months; and it was found that one piece of skin had gained in weight 14 grains and the other 16½ grains. This increase is proportionally much less than that which took place in the experiment on the process of quick tanning. The colour of the pieces of leather was deeper than that of the pieces which had been quickly tanned, and, to judge from the proportions of the residual liquors, more of the extractive matters of the bark had been combined with them.

The other vegetable infusions examined by Sir Humphrey Davy were those of the barks of elm and common willows, of sumach, Mirabola nuts, tea, and some other vegetables of known astringent qualities, the results of which are given in tabulated forms with those of Biggins and Cadet de Gassicourt.

General ob-
servations.

(786.) 5. *General observations.*—Sir Humphrey Davy was led to conclude from the foregoing experiments, that in all the different astringent infusions the tanning principle is possessed of the same general properties and powers of combination. That in the process of tanning, if the astringent infusion contain extractive and colouring matter, these, as well as tannin, enter into chemical combination with the skin: but that in no case is there any reason to believe that gallic acid is absorbed in this process. That hence the different qualities of leather, made with the same kind of skin, seem to depend very much upon the different quantities of extractive and colouring matter it contains; the leather prepared by means of infusion of galls being generally found harder and more liable to crack than that obtained from the infusions of bark. When a skin is very slowly tanned in weak solutions of the barks or of catechu, it combines with a considerable portion of extractive matter, and in these cases, though the increase of the weight of the skin is comparatively small, yet it is rendered perfectly insoluble in water, and is found soft, and, at the same time, strong.

The most essential inference, perhaps, deduced from this inquiry, is, that of all the astringent substances yet examined, the extract of catechu is that which contains the largest proportion of tannin, half a pound of this extract being found to produce the same effect in tanning as from 4 to 5 pounds of common oak bark.

Sir Humphrey Davy concludes his Paper by remarking, with respect to lime water and solutions of pearl-ash, which have been proposed for expediting and improving the process of tanning, that, as these two substances form compounds with tannin which are not decomposable by gelatine, it follows that their effects must be highly pernicious; and there is very little reason to suppose that any bodies will be found which, while they increase the solubility of tannin in water, will not likewise diminish its attraction for the skin.

Proportions of Tannin in different Substances.

Substances.	In 480 by Davy.	* In about 8 ounces by Biggins.	In 100 parts by Cadet de Gassicourt.
White inner Bark of old Oak ..	72	....	21
Ditto, young Oak	77		
Ditto, Spanish Chestnut.....	63	30	
Ditto, Leicester Willow.....	79		
Coloured or middle Bark of Oak	19		
Ditto, Spanish Chestnut	14		
Ditto, Leicester Willow	16		
Entire Bark of Oak	29		
Ditto, Spanish Chestnut.....	21		
Ditto, Leicester Willow	33	109	
Ditto, Elm	13	28	
Ditto, Common Willow.....	11	boughts 31	
Sicilian Sumach.....	78	158	
Malaga Sumach.....	79		
Souchong Tea.....	48		
Green Tea.....	41		
Bombay Catechu, or Japonica.	261		
Bengal Catechu.....	231		
Nut-galls	127	....	46
Bark of Oak, cut in Winter ...	....	30	
Ditto, Beech.....	....	31	
Ditto, Elder.....	....	41	
Ditto, Plum-tree.....	....	58	
Bark of the Trunk of Willow ..	....	52	
Ditto, Sycamore.....	....	53	16
Bark of Beech .....	....	54	
Ditto, Cherry-tree .....	....	59	24
Ditto, Sallow .....	....	59	
Ditto, Poplar.....	....	76	
Ditto, Hazel .....	....	79	
Ditto, Ash.....	....	82	
Ditto, Trunk of Spanish } Chestnut .....	....	98	
Ditto, smooth Oak .....	....	104	
Ditto, Oak, cut in Spring .....	....	108	
Root of Tormentil.....	....	....	46
Cornus Sanguinea of Canada .	....	....	44
Bark of Alder.....	....	....	36
Ditto, Apricot.....	....	....	32
Ditto, Pomegranate .....	....	....	32
Ditto, Cornish Cherry-tree ....	....	....	19
Ditto, Weeping Willow.....	....	....	16
Ditto, Bohemian Olive .....	....	....	14
Ditto, Tan Shrub, with Myr- } tle Leaves .....	....	....	13
Ditto, Virginian Sumach.....	....	....	10
Ditto, Green Oak.....	....	....	10
Ditto, Service Tree.....	....	....	8
Ditto, Rose Chestnut of America	....	....	8
Ditto, Rose Chestnut.....	....	....	6
Ditto, Rose Chestnut of Ca- } rolina .....	....	....	6
Ditto, Sumach of Carolina.....	....	....	6

* See *Philosophical Trans.* 1799.

Mechanica:
Processes.

Manufactures.

(787.) *Process of tanning.*—It is necessary to observe, before we describe these processes, that all tanned leather is technically classed and universally known under the two denominations *hides* and *skins*; the former being commonly applied to the larger animals, as bulls, oxen, cows, &c., which are chiefly intended for the soles of stout shoes and other purposes requiring very thick and solid leather: while the latter term is used for calves, seals, &c., which, being thinner and more flexible, are intended for the upper leather of shoes and boots, for saddles, harness, &c.

Common process of tanning. Butts or bucks.

The heaviest and stoutest of the bull and ox hides are generally selected to make what are technically called *butts* or *bucks*, and are manufactured in the following manner:

When the horns, &c., have been removed, the raw hides are laid in a heap for two or three days, and are then suspended on poles in a close room called a smoke-house, which is heated somewhat above the common temperature by a smothering fire: this occasions incipient putrefaction, which loosens the epidermis, and renders the hair and other extraneous matter easy of separation from the true skin. This is effected by extending the hide on a wooden horse or beam of a convex form, and scraping it with a large two-handled knife called a *fleshing knife*, which is bent to suit the convexity of the beam.

The hides are then immersed in a pit containing water slightly impregnated with sulphuric acid. This operation, which is called *raising*, by distending the pores and swelling the fibres, prepares the hide for the reception of the tannin, and renders it more susceptible of its action.

When the hides are sufficiently *raised*, they are removed into a pit, in which they are laid smooth with a stratum of oak bark, ground to a coarse powder, between each. The pit is then filled with the tanning lixivium, or ooze, prepared from oak bark and water; and the hides remain a month or six weeks without being moved. At the end of this time, the tanning principle being exhausted, the ooze and spent bark are taken out of the pit and the hides put in again, stratified with fresh bark, and covered with fresh ooze as before. Here they remain about three months, when the same process is repeated, at about the same interval, three several times or more, according to the strength of the lixivium and the substance of the hides. When sufficiently tanned they are taken out of the pit, hung up in a shed to dry gradually, and, being compressed with a steel instrument, and beaten smooth, to render them firm and dense, the operation is complete; and, having been numbered, weighed, and stamped by the Excise officer, to ascertain the amount and to mark the payment of the duty, (which will be noticed by and by,) they are ready for sale, and are termed *butts* or *bucks*. These form the thickest and most substantial sole-leather for very strong shoes, and are chiefly intended for exportation.

Dr. Macbride, of Dublin, in a Paper published in vol. lxviii. of the *Philosophical Transactions*, has recommended the use of lime-water instead of plain water in making the oozes, but it does not seem to have been adopted, and, from the result of Sir Humphrey Davy's experiments, it appears rather to be pernicious than useful in expediting and improving the process of tanning.

Crop hides. *Crop hides* are thus manufactured:—The horns having been removed, the hides are immersed in pits containing

a mixture of lime and water, where they remain three or four days, being occasionally moved up and down that each part may be uniformly exposed to the action of the lime-water. They are then taken out of the lime-pit, and the hair, and other extraneous matter, being scraped off on a wooden beam, as before described, they are washed in water to free them from the lime and filth adhering. They are now immersed in a weak ooze, and by degrees are removed into other pits, containing solutions gradually increasing in strength, during which time they are taken up and put down (technically termed *handling*) at least once in every day, that all parts of the hide may be acted upon by the tanning principle equally and uniformly. This is continued for about a month or six weeks, when they are put into other pits with stronger ooze and a small portion of ground bark; whence, as the tannin becomes exhausted, they are removed to others in regular succession, with fresh ooze and fresh bark, for two or three months.

At the end of this period the hides are put into larger vats, called *layers*, in which they are stratified, or laid smooth in a lixivium of greater strength, and with a larger quantity of ground bark between each fold. Here they remain about six weeks, when they are taken up and relaid in the same manner, with fresh bark and strong ooze, for two months. This process is repeated, with little variation, once, twice, or thrice, at the discretion of the manufacturer, till the hides are thoroughly tanned, when they are taken out of the pits, suspended on poles to dry, and, being compressed and smoothed, nearly in the manner before described, are called *crop-hides*, and form the principal part of the sole-leather which is used in England.

The process of tanning *skins* (calves', seals', &c.) is somewhat different from *hides*. They are continued in the lime-pits for ten or fifteen days; they are then depilated and washed in water, after which they are immersed in an infusion of pigeons' dung, called a *grainer*, having the property of an alkali. Here they remain for a week or ten days, according to the state of the atmosphere and other circumstances, during which time they are frequently *handled* and scraped on both sides upon a convex wooden beam. This scraping, or *working*, as it is termed, with the action of the *grainer*, helps to discharge all the lime, oil, and saponaceous matter, and renders the skin soft and pliant, fitted to imbibe the tanning principle. They are now removed into pits containing a weak solution of bark, where they undergo nearly the same process of handling, &c., as *crop-hides*, but they are seldom stratified in layers; and the time occupied in tanning them is usually from two to four months, according to their nature and substance. The skins are then dried and sold to the currier, who dresses and blacks them for the upper leathers of boots and shoes, for harness, and various other purposes.

The light and thin sort of cow-hides and horse-hides undergo nearly the same process in tanning as calf-skins, and are applied to similar uses.

(788.) Mr. John Burbridge published a Work, in the year 1825, termed *The Tanner's Key*, where he explains an improved process of tanning leather, which appears to possess considerable advantages over the common method. It would exceed our limits to give the detail of the process as described in that Work; we shall therefore content ourselves with making an extract of such parts as will afford the reader a clear idea of the general principles and nature of the operation. It appears that the

Mechanical Processes.

Burbridge's process.

Manufac-
tures.

time required to tan a hide is greatly shortened by this process. Mr. Burbridge states that he has a sample of five crop-hides which weighed when raw 477 pounds, and when tanned 295, being 56½ pounds above the standard, or half the raw weight. These hides averaged, therefore, 59 pounds each, and were tanned in 101 days, during a mild Winter, and sold at Leadenhall.

The author observes, that to derive all the practicable benefits from his system, the tan-yard should be provided with a roof and sides to fix in Winter and unfix in Summer, in order to embrace the sun's influence and escape frosts as may be required. Twelve taps of proper sizes are capable of working 24 pits, so as to produce 1500 hides annually, and so on for any larger number that may be required; consequently 24 pits will yield as much leather as 100 by the old method.

"Lime your hides," says Mr. Burbridge, "about a week, then unhair them and let them soak in a brook till next day, then flesh them, and afterwards wash off all the lime again in the brook for an hour or two. Hides will certainly thus be better prepared for immersion in weak liquors, after the lime is well washed away, for lime is no service after unhairing, but, on the contrary, is injurious in my opinion, which corresponds in this respect with that of Sir H. Davy, as appears in his *Lectures on Agricultural Chemistry*."

"When hides are thus prepared, or in the ordinary manner, immerse them as usual in tannin from four to five degrees, and continue handling them frequently; but, in a few days after their first immersion, shift them into rather stronger liquor, (from one to two degrees,) and continue this once or twice a week until the gluten of the hide is dead, or penetrated gradually through, which generally requires two months; during which time they must be handled as often as possible, and sometimes a little bark added in order to keep up the strength and encourage the natural appetites of the hides, which will be destroyed if they are suffered to lie longer in weaker liquors than they have once had, or if shifted into weaker liquors by mistake, which happens daily in common tan-yards."

"You must thus progressively proceed up to liquors of 15°, and sometimes, if necessary, up to 20°, and if the hides, after remaining three days in either of these strong liquors, have not imbibed or reduced the strength in any degree, it is a sure proof that they are quite tanned."

Thus far it appears that in the general character of the process Mr. Burbridge does not vary materially, except in recommending the utmost attention should be paid to the proper strength of the liquors, upon which he considers greatly to depend the time required for the operation, and weight, and quality of the leather; in fact, he reduces the Art to a system, as he observes: "If you throw hides into bark and water, shift them occasionally, and let them lie long enough, they must be turned into leather; but by the use of an instrument employed for this purpose, and proper attention to the strength of the liquors, you may make better leather in four or five months than by the old system in one year."

Mr. Burbridge recommends strongly the use of valonia during the last month of the process for heavy crops.

Suppose hides have been three months tanning, and well struck through, but the centre not quite like the exterior fibres, or perhaps a slight bist in the middle,

which generally defies and protracts the common tanner's utmost exertions, and often consumes many months to tan the centre like the exterior, which is absolutely requisite or it never can be good leather, or command the best prices: in such case Mr. Burbridge recommends the following remedy: "Take 200 pounds of valonia, after being ground in a bark-mill, and put it into a large vat with a coverlid. Heat a copper with 100 or 120 gallons of water, and when boiling pour it into the vat upon the valonia, and cover it to prevent evaporation. Then refill your copper with water, and, when it boils again, in about three hours, draw off the liquor from the vat, and (having previously handled your hides and placed them at the sides of the pit) pour it into the pit with the strongest bark-liquor to be well mixed together; which will not only materially increase the strength of the bark-liquor, but enable it to strike quite through the centre of the hides, adding weight, shortening time, and giving leather a good nutmeg-colour, so much preferred by curriers and shoemakers."

"These further general directions and remarks may be useful. Suspending hides in pits is a very excellent plan, because the tan penetrates quicker by having a free circulation, and there is much less labour in handling or shifting hides when suspended on poles; but hides ought never to be suspended until half tanned, when the centre may be finished quicker that way."

"Make new taps every alternate day or three times a week; put in six baskets of bark the first day, and pump all your taps half round; pump your best or last made tap half into the new one upon the six baskets of bark, half the second tap into the best, and half the third tap into the second, the fourth into the third, and so on all round, as is the common principle in old tan-yards, but avoid the use of plugs, which, although they may save labour, create a much greater evil by preventing the extraction of the strength and virtue of the bark."

Several patents have been taken out both in England and America for improvements in the Art of tanning, generally with a view of further shortening the time of the process. We have given below a description of such as have come into use and seem to deserve particular attention. There are, however, in addition to these, methods employed which are kept entirely secret by the tanners who make use of them, the men in such cases taking the oath of secrecy.

Within a few years many patents have been taken out for methods of expediting the tanning, the most important of which we now propose to mention.

(789.) Mr. Francis G. Spilsbury, of Warshall, Staffordshire, took out a patent, in the year 1823, for a method of obtaining a more rapid action of the tanning liquor by pressure. Oblong square frames are provided, with metal loops fastened round their edges. On one of these a skin or hide is stretched, after being limed, cleansed, and prepared in the usual manner for tanning. Over this hide another of the frames is placed, then a second hide is laid above it, and a third frame is put above that. The three frames are arranged so that the metal loops of each shall be opposite to those of the others; screw bolts are then put through those loops, and screwed up sufficiently tight to prevent any liquor from passing between the frames and the hides. The whole is then set up edgewise, and there being two short pipes furnished with cocks in the upper edge of the middle frame, a pipe, in which there is also a cock that

Mechanica.
Processes.

Spilsbury's
patent.

Man-
fac-
tures.

descends from a cistern holding tan-liquor, is fastened to one of these by a union joint; and another cock being placed near the bottom in the same frame to let off the liquor when required; this completes the whole apparatus.

The cock at the top, which communicates with the tan-cistern, being opened, and the other near it being also opened, while that at the bottom is shut, the tan-liquor will run down between the hides, and drive out the air at the other cock, which as soon as any liquor appears in it is shut; the tan-liquor will then distend the hides, and press outwards with a force depending on the height which the tan-cistern is elevated above the frames.

The consequence of this pressure is that the tan-liquor oozes through the pores of the hides, and appears at the outside like dew; and by bringing fresh portions to act continually on them, causes them to be tanned much more speedily than by the common method, in which the hides lie in the liquor after it has ceased to operate on them, and are only passed into fresh liquor at intervals by a tedious manual operation.

When the skins are sufficiently tanned, the tan-cock is closed and the liquor run off at the lower cock; the frames are then separated from the tan-pipe, and from each other, and the hides being removed and their edges pared off, which were nipped or compressed between the frames, are then to be dried and finished in the usual manner.

This method of tanning has attracted much attention, and it is stated that hides of sufficient thickness to require a year for tanning in the common method can be finished in this way in six weeks, and that some skins may be tanned by it in eight or nine days.

The theory of the process seems to promise well for quick performance, but we have been informed, by some gentlemen in the trade, that the skins are not tanned evenly by this method, but that spots are left which are less acted upon by the liquor than others, and that leather made in this way is not so durable as the common sort.

The quantity of the hides which must be pared when they come out of the frames must certainly diminish the value of the process, and especially when oblong square frames (such as are represented in the figure of the specification) are used, which not being of the natural shape of the hides, must cause more waste; this is certainly worth consideration, although the parts to be cut away are the least valuable of the hides.

Knowles and
Duesbury's
patent.

(790.) A patent was granted to Thomas John Knowles, Esq. of Trinity College, Oxford, and William Duesbury, of Ronsal, Derbyshire, for improvements in tanning. In this method the hides are suspended vertically in a covered air-tight vat; from which, after a sufficient quantity of tan-liquor is admitted so as to rise a little above the hides, the air is exhausted by an air-pump, which, extracting the air from the pores of the hide, causes them to imbibe the tan-liquor more rapidly and effectually.

The vat for this purpose must be somewhat deeper than the broadest hides, and its breadth must exceed a little their greatest length, while its length must be determined by the number of hides that are required to be suspended in it at the same time. Along the upper part of its opposite sides, hooks are fixed to support the hides by their upper angles, and in the middle of its top an aperture is made by which a man may go down to suspend the hides on the hooks, or to clean out the

vat; a cover is fitted into this aperture, round the edges of which leather is fastened, to prevent air from entering after it is fixed in its place. From the upper part of one side of the vat, a pipe furnished with a cock passes to an air-pump; from the top of the opposite side another pipe proceeds outwards a few inches, by which air may be admitted when required, and which likewise is closed by a stop-cock; and from the bottom of the vat a tube passes to the bottom of a pump, by which the tan-liquor may be drawn out after it is used. The patentees state that the vat may be made of any substance except iron, but it is not likely that any other material but wood will be employed in its fabrication.

When the vat is thus prepared the hides are to be suspended across it on hooks within small distances of each other, and lead weights are to be fastened to the bottom of each of the sides at regular intervals asunder, to keep them down evenly in their places; the tan-liquor is then to be run into the vats until it rises above the hides to within two or three inches of the top, and the cover is to be closed down over the main passage; after which the air-pump is to be worked until the air is sufficiently exhausted from the vat. In this state the whole is to be left for about twenty-four hours, after which the tan-liquor is to be pumped out, first opening the pipe for the admission of air, and then the vessel is to remain empty for two or three hours, to permit the hides to imbibe air again in their pores; and this process is to be repeated successively until the hides are sufficiently tanned. At first weak tanning liquor is to be used, and its strength is to be increased as the tanning of the hides advances. The patentees find it useful to put a little oil on the top of the liquor in the vat, to prevent bubbles issuing from it, so as to make the liquor run into the air-pipe when the air is being exhausted.

This method of tanning seems to be founded on very just principles, and to be likely to tan the hides completely, from its causing the tan-liquor to act equally on every part of them at the same time, while the exhaustion of the air as directed will, we should suppose, much accelerate the operation. We are not, however, acquainted with the precise ratio in which this process exceeds in rapidity that in common use.

(791.) A patent was granted to William Brown, of the City of New York, America, for a labour-saving tanning apparatus. The improvement consisted in connecting and concentrating various processes through which the hides pass before they become leather, by means of suitable apparatus, the construction of which is as follows:

For infusing the bark there are four or more leaches, or cisterns, which are placed contiguous to the handlers or vats on the same level, but projecting at the top above them. These leaches, or cisterns, communicate with each other by means of tubes, inserted between them near the tops, and are supplied with false bottoms, which fit loosely, and which are perforated with holes, forming a kind of strainer. In each of the leaches is fixed an aqueduct, or tube, which is used to convey the liquor from the bottom to the communicating tubes. By this contrivance the liquor is passed from the bottom of one leach into the top of the adjoining one, where it acquires a fresh portion of strength, and is thus propelled through the whole series, by pouring the water or weak liquor into the tops of the leaches, until, being of sufficient strength, it arrives at the fourth or strongest

Mechanical
Processes.

Manufac-
tures.

leach. There is also placed in one corner of each of these leaches what is called an eye, which consists of a trunk projecting below the bottom of the leach, and connected to a horizontal pipe, which serves to convey the liquor, when of sufficient strength, directly to the handlers or vats; this trunk is supplied with a plug for regulating the quantity of liquor thus drawn off.

At a convenient distance from the leaches, and on the same level with them, is placed a heater, which consists of two or more horizontal copper or iron pipes, placed one above the other, and having connecting tubes near their ends. These pipes are attached to and communicate with another of a square form, in which the fire is made, and they are secured within a cistern, with their ends projecting at one side, and have caps for the convenience of cleaning.

It will be seen that, when the fire is kindled in the lower heater or box, the heat passes from it into the tube above at its furthest extremity, and comes forward and enters the next above, and so goes backward and forward until it enters the chimney at the opposite side, thus transmitting all the heat of the fire to the liquor with which the cistern is constantly filled. There is a tube communicating with the heating cistern for supplying it with weak liquor or water, which communicates at its opposite extremity with a trunk or reservoir, furnished with a pump, by which the liquor is raised to the tube and forced into the heated cistern, which is kept constantly full by this means; the heated liquor passing off at a different tube, which communicates directly with the leaches. The leaches are filled with bark by means of a conveying trough communicating with the elevators of the mill. The strong liquor or infusion passes from the bottom of the leaches, as before mentioned, into a trunk, passing into a horizontal position under them, and rises by a vertical tube inserted in the said trunk, from which it is transmitted to another horizontal trunk communicating with the handlers or vats, passing along their upper surfaces. By this method the liquor from the leaches is transmitted into the tops of the handlers or vats. At the bottom of the vertical tube, and within the lower horizontal trunk, is placed a valve, movable by means of a strap extending up through the said tube, which is to prevent the stronger liquor from entering the reservoir, and thus mixing with the weaker.

The liquor, after having passed through the handlers or vats, is drawn from their taps by means of a hollow plug inserted into the lower trunk before mentioned, and runs into the trunk or cistern, whence it is again transmitted to the heaters, and so on to the leaches; so that the same liquor is continually in use, the evaporation and waste of which is supplied by water.

In each of the handlers is a reel or cylinder, formed by two circular heads, secured at the required distance apart by longitudinal bars, and having gudgeons which work in slides for the convenience of elevating or depressing them at pleasure. The hides are secured on the inside of the reels by means of hoops, which encircle the reels a short distance from their heads, and have pins on their outer surfaces by which the hides are fastened; or they may be thrown loose into the reels.

The great saving of labour in this invention consists in the facility with which the hides may be kept in motion when immersed in liquor. Each of the reels has a ratchet wheel attached to it, and is turned one

VOL. VII.

notch at a time, by means of a shaft, which is geared into a link, to be worked by hand, or may be moved by animal, water, or steam power. The piston of the pump in the trunk or reservoir is attached to one of the shafts, and may be moved or unshipped at pleasure.

There is what is called a beam-house connected with this apparatus, where the hides are first limed before they are put on reels. The water which is necessary to mix the lime is heated and supplied on the same principle as that before mentioned for the leaches; and the piston of the pump is attached in a similar manner to the shaft. In laying away hides it is necessary to have the ground bark which is put between them moistened or damped, to prevent waste and dust. The contrivance for this purpose consists of a small cistern, elevated at a convenient height, and supplied with a spout perforated with holes, and a cock for regulating the quantity of water required to wet the bark, which is placed under it. The patentee claims the privilege of using his improved labour-saving apparatus on as large or small a scale as he may require, and with any number of leaches and handlers.

(792.) The most recent patent for improvements in tanning of any importance was granted to Mr. William Drake, tanner, of Bristol, dated October 7, 1831. The nature of the invention consisted in causing tannin to enter the hides or skins by supplying cold tan liquor to one side, and evaporating by artificial heat from the other side a portion of the moisture which oozes through it, whereby the strongest portion of the tannin is left in the skin, while the strength of the liquor continually increases during the tanning process, instead of becoming weaker, as in the ordinary case of proceeding.

By this improved process the patentee states a hide or skin may be tanned in ten days as completely as would require ten months to perform by the usual method. The manner of conducting the process he thus describes:

The skins and hides intended to be tanned, after undergoing the usual processes of liming, &c., are immersed in a backward or weak tan liquor, with frequent and continued handling: they thus become saturated with liquor, and receive their preparatory colouring before their intended submission to the improved process. The skin is then to be carefully examined, and should any holes be found in it, they are to be sewed up, or otherwise stopped, in order to prevent the liquor with which they are intended to be filled from escaping, except through the pores of the hide.

Should it be intended to tan the hides as butts, middlings, or any other shape than the natural one, the intended shape must be given at this part of the process, by rounding or cutting off the extraneous parts.

Some other patents for improvements in tanning, both English and American, might be enumerated, which our limits will not permit us to describe, and we beg to refer the reader to the *Repertory of Arts*, where all deserving of notice are given either in the words of the specification, or in such a description as will perfectly explain the views of the inventor.

Tawing, Currying, Leather-dressing, &c.

(793.) The dressing and preparation of the skins of lambs, sheep, goats, and other thin hides, although in many particulars closely resembling the methods we have described, forms usually a totally distinct branch of

Mechanica
Processes.

Tawing,
currying
&c.

Manufac-
tures.

business, and is one in which a good deal of practical skill and nicety of manipulation are required to succeed perfectly: we are indebted for the following account of these processes to Aikin's *Chemical Dictionary*.

The processes are very various, according to the article required, and this branch of the manufacture supplies the immense demand of white and dyed leather for gloves; that termed Morocco leather, of different colours and qualities, for coach-lining, bookbinding, pocket-books, &c.; and thin leather for an infinite number of smaller purposes. Of these, the white leather alone is not tanned, but finished by the process of tawing; but the coloured leather always receives a tanning (generally by sumach) independently of the other dyeing materials. The previous preparation of each, or that in which the skin is thoroughly cleansed and reduced to the state of simple membrane, in which it is called *pelt*, is essentially the same whether for tawing or dyeing. It is thus performed at the best manufactories at Bermondsey, near London, a place long celebrated for all branches of the leather business.

Lamb-skins.

Lamb-skins are prepared by first soaking them for a time in water to remove any loose dirt and blood, and then placing them upon a beam composed of a half cylinder of wood covered with strong leather, and scraped on the flesh side with the semicircular blunt knife, commonly used in this operation. They are then hung up in considerable numbers in a small close room heated by flues, where they remain to putrefy for a given time. During this process a thick filthy slime works up to the surface of the skin, by which the regularity of the process is judged of, and the wool is loosened so that it readily comes off with a slight pull. Each skin is then returned to the beam, the wool taken off and preserved, and all the slime worked off with the knife, and the rough edges pared away. The skin is then put into a pit filled with lime-water, and kept there from two to six weeks, the time depending upon the nature of the skin: this has the effect of checking the further putrefaction, and produces a very remarkable hardening and thickening of its substance, and probably, also, it detaches a further portion of the slime. The skin is again well worked upon the beam, and much of its substance pared down, and all inequalities smoothed with the knife. Much care and judgment are required in these operations; on the one hand not to endanger the substance of the skin by the putrefaction, which, if carried on too long, would soon reduce it to an incohesive pulp; and on the other hand to work out every particle of the lime, the least of which, if retained, will prevent the skin from dressing well in the subsequent processes, and from taking the dye uniformly.

The skin is then again softened by being thrown into a vat of bran and water, and kept there for some weeks in a state of gentle fermentation, being occasionally returned to the beam. All the thickening produced by the lime is thus removed, and the skin is now as highly purified as possible, and becomes a thin extensible white membrane, called in this state the *pelt*, and is now fit for any subsequent operation of tawing, dyeing, oil-dressing, or shammying.

Kid and
goat skins.

The method of bringing kid and goat skins in the state of *pelt* is nearly the same as for lambs, except that the liming is used before the hair is taken off, the hair being of no great importance, and sold only to plasterers, but the lamb's wool, which is more valuable, would be injured by the lime.

If the pelts are to be tawed, they are then put into a solution of alum and salt in warm water, in the proportion of about 3 pounds of alum and 4 pounds of salt to every 120 middle-sized skins, and worked about in it till they have absorbed a sufficient quantity. This again gives the skin a remarkable degree of thickness and toughness. The skins are then taken out and washed in water, and then again put into a vat of bran and water, and allowed to ferment for a time, till much of the alum and salt is got out, and the unusual thickness produced by it is for the most part reduced. They are then taken to a lofty room with a stove in the middle, and stretched on hooks, and kept there till fully dry, when they become tough and flexible, and quite white leather; but to give them a glossy finish, and to take off the harshness of feel still remaining, they are again soaked in water to extract more of the salt, and put into a large pail containing the yolks of eggs beat up with water. Here the skins are sodden for a long time, by which they so completely imbibe the substance of the egg that the liquor above them is rendered almost limpid; after which they are hung up in a loft to dry, and finished by glossing with a warm iron, which completes the operation.

The essential difference, therefore, between tanning and tawing is, that in the former case the pelt is combined with tan and other vegetable matter, and in the latter with something that it imbibes from the alum and salt, (probably alumine,) and which certainly is never again extracted by the subsequent washing and branning.

(794.) *English Morocco leather*.—The leather called English Morocco leather, which is chiefly prepared from sheepskins, and used so largely for coach-lining, pocket-books, and the best kind of bookbinding, is thus made. The skin, cleansed and worked in the way already described, is taken from the lime-water, and the thickening thereby occasioned is brought down, not by bran liquor, as in tawing, but by a bath of dog's or pigeon's dung, diffused in water, where it remains till sufficiently supplied, and till the lime is quite got out, and it becomes a perfectly clean white pelt. If intended to be dyed red, it is sewed up very tight in the form of a sack with the grain side outwards, (the dye being required only on this side,) and is immersed in a cochineal bath of a warmth just equal to that which the hand will bear, and is worked about until it is uniformly dyed, a process that demands much skill and experience. The sack is then put into a large vat, containing sumach infused in warm water, and kept for some hours until sufficiently tanned. The skins intended to be blacked are merely sumached, without any previous dyeing.

After some further preparation, the colour of the fine red skins being finished with a weak bath of saffron, the skins, when dried, are grained and polished in the following manner. They are stretched very tight upon a smooth inclined board, and rubbed over with a little oil to render them supple. Those intended for black leather are previously rubbed over with an iron liquor, by means of a stiff brush, which, uniting with the gallic acid of the sumach, instantly strikes a deep and uniform black.

They are then rubbed by hand with a ball of glass cut into a polygonal figure, which polishes them, and makes them very firm and compact. Lastly, the graining or ribbed surface, by which this kind of leather is distinguished, is given by rubbing the leather very strongly with a ball of box-wood, round the centre

Mechanical
Processes.
Tawing.

English
Morocco
leather.

Graining
and po-
lishing.

Manufac-
tures.

of which a number of small equidistant parallel grooves are cut, forming an equal number of narrow ridges, the friction of which gives the leather the desired inequality of surface.

Currying
leather.

(759.) *Currying leather*.—The common mode of currying leather for shoes, boots, &c., consists in first softening the hides, as they come from the tan-pit, by soaking them thoroughly in water; they are then placed on a polished beam with the flesh side outwards, and pared with a broad sharp knife, till all the inequalities are removed and it is reduced to the required thinness. They are then again rubbed and washed with a polished stone, and, while still wet, are besmeared with currier's oil, generally fish oil, or a mixture of this with tallow, which renders them much more impervious to moisture, and proper to protect the feet against the inclemency of the weather. They are afterwards hung up to dry, by which the moisture is evaporated, but the oil, which cannot be dissipated by mere exposure, gradually takes the place of the moisture, and penetrates deeply into the pores of the leather. It is then dried either in the sun or in a stoved room.

Blackening the leather is also a part of the currier's business, which is done on the grain side simply by rubbing it with an iron liquor, but on the flesh side with a mixture of lamp-black and oil.

Common boot leather, as usually prepared, is, however, still, in some degree, pervious to water, by long exposure to wet, and for this reason fishermen, wild-fowl shooters, and those whose employment or amusement leads them to be long on wet ground, usually prepare their boots with an additional dressing of some oily or viscous matter.

Shammoyed leather.—This is generally prepared from sheep or does' skin prepared in the way already mentioned by dressing, liming, &c., and dyed if necessary, and then finished with oil. This forms the common wash leather, breeches leather, &c., and is the only kind which, when dyed, will bear washing without the colouring being materially injured.

We add the following particulars relative to the manufacture of some of the most remarkable kinds of leather prepared in foreign Countries, which, although in most respects closely resembling ours, have distinct points of difference, which will be interesting both to the English manufacturer as well as to the general reader.

Real Mo-
rocco lea-
ther.

(796.) *Real Morocco leather*.—The process for the preparation of this leather from the goat-skins at Fez and Tetuan is thus described by M. Broussonet:—The skins are first cleansed, the hair is taken off, limed, and reduced with bran, nearly in the way already described for the English Morocco leather. After coming from the bran they are thrown into a second bath made of white figs, mixed with water, which is thereby rendered fermentable, in which they remain four or five days, and they are then thoroughly salted with salgum (or rock-salt) alone, in lieu of the salt and alum; after which they are fit to receive the dye, which, for the red, is cochineal and alum, and for the yellow pomegranate-bark and alum; the skins are then tanned, supplied with a little oil, and dressed.

Russia leather.—Much excellent leather of every kind is prepared in different parts of the Russian Empire. The preparation of the fine Russian leather, so well known for its quality and for its peculiar smell, is described at large in Mr. Tooke's *View of the Russian*

Empire, to which we must refer the reader for the minutiae of the processes. The hides are first put into a weak alkaline ley to loosen the hair, and then scraped on a beam; then (if calves) are reduced by dog's dung and a sour oatmeal drench, and tanned with great care and frequent handling; the bark used here is seldom oak, that of the black willow being preferred; but if this cannot be obtained, they use the birch bark. They are then either dyed red or black, these being the two colours most esteemed. For the red the hide is first soaked in alum, and then dyed with Brazil wood, and the black is given as usual with an iron liquor. The leather is then smeared with birch bark, which gives the peculiar smell so much prized, and which, when used for bookbinding, has the valuable property of protecting the book from worms. The streaked or barred surface is given to the leather by a very heavy steel cylinder wound round with wires.

A valuable Saffian or dyed Maroquin leather, almost equal to that of Turkey, is prepared at Astracan and in other parts of Asiatic Russia. Buck and goat skins are the only ones used for this purpose, and the favourite colours are red and yellow. The general method of preparing the pelt is the same as used in this Country for the dyed Morocco leather; that is, by lime, dog's dung, and bran. Honey also is used after the branning; it is dissolved in warm water, and some of the liquor poured on each skin, spread out on wooden trays, till it has imbibed the whole of the honey, after which it is permitted to ferment for about three days, and then salted in a strong brine and hung up to dry. The skin is then ready to receive the dye, which for red is made with cochineal and the *Salsola ericoides*, an alkaline plant growing plentifully on the Tartarian salt deserts, and the colour is finished with alum. When dried, the skins are generally tanned with sumach, but for the very finest reds a quantity of sorrel is used with the cochineal bath, and the subsequent tanning is given with galls instead of sumach, which render the colour as durable as the leather itself. The roughness always observed on the surface of the skin is given by a heavy kind of iron rake with blunt points. The yellow Saffians are dyed with the berries of a species of *rhamnus*, (the Avignon berry would answer the same purpose, and is used in other Countries,) or with the flowers of the wild camomile.

(797.) *Shagreen leather*.—This singular and valuable leather is a manufacture almost peculiar to Astracan, where it is prepared by the Tartars and Armenians. For making shagreen only horses' or asses' hides are taken; and it is only a small part, from the crupper along the back, that can be used for this purpose, which is cut off immediately above the tail in a semicircular form, about 34 inches upon the crupper, and 28 along the back. These pieces are first soaked in water till the hair is loose and can be scraped off, and the skin, after being again soaked, is scraped so thin as not to exceed a wetted hog's bladder in thickness, and till all the extraneous matter is got out, and only a clean membranous pelt remains. The piece is then stretched tight on a frame, and kept occasionally wetted, that no part may shrink unequally. The frames are then laid on a floor with the flesh side of the skin undermost, and the grain side is strewed over with the smooth black hard seeds of the *Ala lenta* or goose foot, (*Chenopodium album*), and a felt is then laid upon them, and the seed trodden deeply into the soft moist skin, which gives the peculiar mottled surface

Mechanical
Processes.

Shagreen
leather.

Manufac-
tures.

for which shagreen is distinguished. The frames, with the seeds still sticking to the skin, are then dried slowly in the shade, till the seeds will shake off without any violence, and the skin is left a hard horny substance with the grain side deeply indented. It is then laid on a solid block covered with wool, and strongly rasped with two or three iron instruments, till the whole of the grain side is shaved, so that the impression of the seeds is very slight and uniform; the skins are then softened first with water, and then with a warm alkaline ley, and are heaped warm and wet on each other, by which means the parts indented by the impression regain much of their elasticity, and, having lost none of their substance by paring, rise up fully to the level of the shaved places, and thus form the grain or granular texture peculiar to the shagreen. The skin is then salted and dyed.

The beautiful green colour is given by soaking the inner or flesh side of the skin with a saturated solution of sal ammoniac, strewing it over with copper filings, rolling it up with the flesh side inwards, and pressing each skin with a considerable weight for about 24 hours, in which time the sal ammoniac absorbs enough of the copper to penetrate the skin with an equable sea-green colour. This is repeated a second time to give the colour more body. Blue shagreen is dyed with indigo, dis-

solved in an impure soda by means of lime and honey. Mechanical Black shagreen is dyed with galls and vitriol; they are Processes. in each case finished with oil or suet.

We conclude this section with the following Tables of the amount of duty on hides and skins, quantities imported and exported, &c. &c., from 1820 to 1831 inclusive.

(798.) *Quantities of Goats' Skins, Horse and Cow Hides, tanned, tawed, and dressed in Oil, charged with Duties of Excise, and Net Produce of Duties in each Year, from 1820 to 1831, both inclusive:—*

Years.	Pounds of Hides and Skins.	Amount of Duty.
1820.....	49,388,059.....	£608,158
1821.....	48,921,373.....	600,282
1822.....	46,422,645.....	546,503
1823.....	57,232,170.....	393,657
1824.....	63,017,469.....	434,481
1825.....	68,903,650.....	443,000
1826.....	59,177,421.....	378,975
1827.....	61,454,676.....	393,516
1828.....	64,633,422.....	414,863
1829, to 5th July..	60,143,253.....	396,207
1830.....	19,403,590.....	194,678
Returns for 1831 not given.		

(799.) *An Account of Quantities of Untanned Hides imported into and exported from the United Kingdom, the Quantities entered for Home Consumption, the Rates of Duty, and the Net Produce thereof in each Year, commencing 5th January, from 1820 to 1831, both inclusive.*

Years.	Imported.		Exported.		Consumption.		Rates of Duty.							Net Revenue.
	Buffalo, Bull, Cow, Ox, or Horses' Hides.	Hides or Pieces of Hides unenumerated.	Buffalo, Bull, Cow, Ox, or Horses' Hides.	Hides or Pieces of Hides unenumerated.	Buffalo, Bull, Cow, Ox, or Horses' Hides.	Hides or Pieces of Hides unenumerated.	Buffalo, Bull, Cow, Ox, or Horses' Hides.				Hides or Pieces unenumerated.			
	Number.	Value. £.	Number.	Value. £.	Number.	Value. £.	From the West Coast of Africa.	Of Places within the Limit of the East India Company's Charter.		Otherwise imported.	From British Possessions in America.	From other Places.		
							Buffalo, Bull, Cow, or Ox Hides.	Buffalo, Bull, Cow, or Ox Hides.	Horses' Hides.	All Sorts.	Per Centum.	Ad valorem.		
1820	636,766	469	166,519	..	501,881	469	6d. each.	6d. each.	10d. each.	10d. each.	£. s. d. 5 17 6	£. s. d. 20 0 0	2,095	
1821	955,904	713	150,448	..	821,254	713	,,	,,	,,	,,	,,	,,	32,796	
1822	1,434,481	1,087	123,045	..	1,146,782	1,087	,,	,,	,,	,,	,,	,,	46,110	
1823	1,157,164 and Cwts. 86,667	2,679	160,491	..	869,813 and Cwts. 63,234	2,679	Of the West Coast of Africa, not exceeding 14lbs. each. Per Cwt. 2s. 4d.	Of other Places. Dry. Per Cwt. 4s. 8d. Wet. Per Cwt. 2s. 4d.			,,	,,	45,412	
1824	303,228		Cwts. 49,110	35	Cwts. 271,044		2,560	,,	,,	,,	,,	,,	,,	47,375
1825	303,693	3,555	38,380	1,392	277,818	2,441	Of the West Coast of Africa, not exceeding 14lbs. each. Per Cwt. 2s. 4d.	Of British Possessions. Dry. Per Cwt. 2s. 4d. Wet. Per Cwt. 1s. 2d.		Of other Places. Dry. Per Cwt. 4s. 8d. Wet. Per Cwt. 2s. 4d.	,,	,,	42,073	
1826	194,244	1,751	29,303	634	169,338	1,117	,,	,,	,,	,,	,,	,,	23,237	
1827	152,315	1,174	9,663	114	169,834	1,060	,,	,,	,,	,,	,,	,,	26,105	
1828	225,938	267	10,243	30	214,726	237	,,	,,	,,	,,	,,	,,	34,569	
1829	286,417	831	40,634	..	231,874	813	,,	,,	,,	,,	,,	,,	37,131	
1830	339,773	2,967	45,747	2,549	277,631	418	,,	,,	,,	,,	,,	,,	42,154	
1831	271,469	632	47,788	11	236,099	621	,,	,,	,,	,,	,,	,,	32,505	

Manufac-
tures.

(800.) *An Account of the Quantity of Tanned Hides imported into and exported from the United Kingdom, the Quantities entered for Home Consumption, the Rates of Duty, and the Net Produce thereof, commencing 5th of January, from 1820 to 1831, both inclusive.*

Mechanical
Processes.

Buffalo, Bull, Cow, Ox, or Horse, Tanned.						
Years.	Importations.	Exportations.	Consumption.	Rates of Duty.		Net Revenue.
	lbs.	lbs.	lbs.	Per lb.		£.
1820	6,788	.	6,788	1s.		339
1821	.	265	.	"		
1822	300	.	300	"		15
1823	6,563	.	.	"		
1824	61,256	50,964	87	"		4
				Of Foreign Countries.	Of British Possessions.	
1825	86	11,154	9,993	1s.	6d.	241
1826	.	1,814	.	"	"	
1827	11,139	10,748	85	"	"	3
1828	17,208	9,904	3,495	6d., and if cut or trimmed 9d.	3d., and if cut or trimmed 4½d.	84
1829	6,427	256	6,929	"	"	152
1830	37,391	1,346	29,002	"	"	392
1831	15,056	.	23,983	"	"	304

Muscovy or Russia Hides Tanned or Coloured.						
Years.	Importations.	Exportations.	Consumption.	Rates of Duty.		Net Revenue.
	lbs.	lbs.	lbs.	Per lb.		£.
1820	94,965	87,611	.	1s. 8d.		2,772
1821	29,909	287	.	"		2,463
1822	15,013	148	.	"		2,474
1823	Number.	Number.	{ 20,216 } Number.	1s. 3d. each.		1,483
	2,973	.	54			
1824	2,937	.	682	"		511
1825	6,598	.	3,701	"		2,747
1826	1,950	306	2,290	"		1,717
1827	1,506	12	2,920	"		2,190
1828	7,621	4,117	3,516	"		2,396
1829	8,199	1,800	6,577	Hides 5s. each.	Pieces 2s. 6d. per lb.	2,228
1830	1,096	115	3,420	"		852
1831	3,219	.	2,879	"		720

Hides or Pieces of Hides enumerated, Tanned, Curried, or Dressed.									
Years.	Importations.		Exportations.		Consumption.		Rates of Duty.		Net Revenue.
	Value. £		Value. £		Value. £				£
1820	.		.		.		£75 per Centum, ad valorem.		.
1821	508		.		508		"		381
1822	4,658		1,913		2,745		"		1,957
1823	2,472		436		5,416		"		4,281
1824	533		528		6		"		4
1825	290		130		160		"		120
1826	264		258		6		"		5
1827	189		153		36		"		27
							Tawed, Curried, or Dressed. Of British Possessions.	Of Foreign Countries.	Tawed, Curried, Tanned or Dressed, unenumerated.
1828	242		200		42		{ 9d. per lb., and if cut or trimmed 1s. 2d.	4½d. per lb., and if cut or trimmed 7d.	{ £75 per cent. ad valorem. }
	Value. £	Weight. lbs.	Value. £	Weight. lbs.	Value. £	Weight. lbs.			
1829	266	67	265	..	1	67	"	"	{ £40 per cent. ad valorem. }
1830	93	27,914	93	..	..	..	"	"	
1831	..	47,583	..	39,958	..	20	"	"	1

Manufac-
tures.

(801.) *An Account of the Quantity of the undermentioned Skins Imported into and Exported from the United Kingdom, and cleared for Consumption, together with the Rates of Duty, and the net Amount of Revenue thereon, in each Year, commencing on the 5th January, from 1820 to 1831 both inclusive.*

Mechanical
Processes.

Calf or Kip Untanned.									
Years.	Importations.		Exportations.		Consumption.		Rates of Duty.		Net Revenue.
	Number.		Number.		Number.		Calf.	Kip.	£.
1820	587,238		580		572,723		2d. each.	6d. each.	4,928
1821	632,444		....		622,332		"	"	5,933
1822	745,414		16,512		737,598		"	"	9,579
							Calf or Kip per Cwt.		
								Of the W. Coast of Africa.	
1823	{ 514,208 Cwts. qrs. lbs. 6,658 1 18 }		44,160		{ 399,563 Cwts. qrs. lbs. 7,802 3 21 }		Dry. 4s. 8d.	Wet. 2s. 4d.	2s. 4d. 7,112
1824	22,664 1 0		1,957 3 24		25,071 1 12		"	"	4,287
1825	31,399 3 0		....		31,411 0 19		"	"	5,290
1826	19,392 1 10		....		19,278 2 23		{ British Possessions. 2s. 4d. 1s. 2d. Other Parts. 4s. 8d. 2s. 4d. }		3,111
1827	34,285 3 16		....		35,040 3 19		"	"	6,646
1828	50,166 2 14		234 0 6		49,444 3 3		"	"	9,831
1829	43,754 3 10		160 1 24		43,046 2 4		"	"	8,072
1830	32,395 0 24		332 1 25		32,417 2 1		"	"	6,184
1831	42,637 1 27		934 0 16		40,193 3 19		"	"	8,512

Calf and Kip Tanned.					
	lbs.	lbs.	lbs.	per lb.	£.
1820	20,277	....	20,277	1s.	1,014
1821	16,435	....	16,435	"	822
1822	5,806	....	5,806	"	290
1823	2,707	....	2,707	"	135
1824	8	....	8	"	
1825	8,357	4,272	4,085	"	204
1826	50	....	50	"	2
1827	386	....	386	"	11
1828	1,309	412	865	{ Varied according to the state of skin, place of ex- portation, &c. The average being a little under 9d. }	39
1829	5,254	309	4,945		204
1830	4,501	1,834	2,667		105
1831	10,283	1,015	9,268		219

Deer Undressed.						
				Of British Possessions in America.	Of other Parts.	
	Number.	Number.	Number.	s. d.	s. d.	£.
1820	84,305	61,407	72,264	0 2 each	0 4 each.	944
1821	51,263	35,141	50,505	"	"	814
1822	78,304	53,179	41,825	"	"	688
1823	75,980	18,984	41,736	"	"	692
1824	83,488	30,078	68,839	"	"	1,125
1825	116,900	14,958	60,283	"	"	976
1826	166,199	80,227	106,921	"	"	883
1827	121,243	66,270	51,922	1 0 per 100	0 2 each.	403
1828	78,618	62,470	23,932	"	"	202
1829	123,276	101,387	36,314	"	"	323
1830	124,618	80,353	27,649	"	"	258
1831	125,357	112,948	31,079	"	"	259

Manufac-
tures.Mechanical
Processes.

Goat Undressed.					
Years.	Importations.	Exportations.	Consumption.	Rates of Duty.	Net Revenue.
	Number.	Number.	Number.	s. d.	£.
1820	175,809	60	141,710	2 10 per dozen.	1,680
1821	371,769	3,720	339,203	" "	4,011
1822	214,817	13,081	243,580	" "	2,827
1823	150,065	9,636	133,868	" "	1,584
1824	155,191	62,535	150,714	" "	1,771
1825	367,212	56,511	210,172	" "	2,481
1826	157,795	13,372	169,329	" "	1,999
1827	245,626	57,132	225,719	" "	2,686
1828	299,301	39,903	248,811	" "	3,021
1829	306,579	113,724	182,062	" "	2,203
1830	290,857	62,924	205,734	" "	2,457
1831	354,584	97,469	212,422	" "	2,522
Kid in the Hair.					
	Number.	Number.	Number.	s. d.	£.
1820	234,932	....	244,084	1 7 per 100.	193
1821	359,464	....	358,293	" "	284
1822	447,076	....	448,224	" "	352
1823	510,052	....	482,240	" "	339
1824	243,931	714	315,837	" "	250
1825	375,094	1,444	368,514	1 6 per 100.	262
1826	247,369	....	247,768	" "	187
1827	477,989	29,279	455,737	" "	364
1828	339,020	818	337,826	" "	254
1829	106,319	....	107,513	0 4 per 100.	25
1830	223,951	280	223,671	" "	37
1831	595,573	71,955	486,527	" "	86
Kid Dressed.					
	Number.	Number.	Number.		£.
1820	334,527	....	334,527	£2 per 100.	6,667
1821	275,324	....	275,324	" "	5,507
1822	441,366	....	441,366	" "	8,832
1823	517,844	....	517,844	" "	10,355
1824	650,283	....	650,283	" "	13,015
1825	796,206	....	796,206	" "	7,432
1826	603,277	....	603,277	{ Dyed or co- loured, 15s. Not dyed or co- loured, 10s. }	3,018
1827	648,480	....	648,100	" "	3,190
1828	566,889	192	566,701	" "	2,833
1829	591,094	379	591,091	" "	2,955
1830	862,538	....	862,538	" "	4,327
1831	621,780	....	621,780	" "	3,102
Lamb Undressed.					
	Number.	Number.	Number.	Per Cent. <i>ad valorem</i> .	£.
1820	888,663	....	926,201	£20	7,564
1821	1,162,758	....	1,158,728	" "	9,032
1822	1,830,408	100	1,834,438	" "	14,819
1823	2,420,135	1,550	1,919,778	14s. per 100.	13,389
1824	1,679,399	10	2,088,379	" "	14,616
1825	1,866,223	390	1,892,469	10s. 6d.	2,480
1826	1,678,865	....	1,697,409	" "	1,282
1827	2,599,379	388	2,595,765	" "	1,947
1828	2,770,112	1,524	2,773,306	" "	2,070
1829	1,888,191	300	1,887,891	4d.	407
1830	1,804,714	760	1,803,385	" "	282
1831	2,820,092	1,609	2,819,706	" "	470

Manufac-
tures.Mechanical
Processes.

Lamb Tanned, Tawed, or Dressed.						
Years.	Importations.	Exportations.	Consumption.	Rates of Duty.		Net Revenue.
				Tanned or Tawed.	Dressed in Oil.	
	Number.	Number.	Number.	Per 100.	Per 100.	£.
1820	6,616	....	6,616	£2	£4	132
1821	3,303	....	3,303	„	„	66
1822	18,213	....	18,213	„	„	364
1823	42,883	....	42,883	„	„	858
1824	112,989	....	112,989	„	„	2,261
1825	207,318	....	205,714	10s.	„	1,157
				Dyed or Coloured.	Not Dyed or Coloured.	
1826	46,233	....	47,837	15s.	10s.	239
1827	156,234	....	153,318	„	„	769
1828	143,562	....	142,978	„	„	717
1829	42,503	724	42,499	„	„	218
1830	56,465	2,780	56,465	„	„	282
1831	73,228	....	73,228	„	„	368

Seal Undressed.						
	Number.	Number.	Number.			£.
1820	322,448	12,285	318,723	{Of British taking, and imported directly from Newfoundland, 1d. ea., but suspended until 5th July, 1824.	Otherwise imported, 3d. each. }	1,603
1821	568,278	6,004	555,533	„	„	3,890
1822	371,694	6,017	380,891	„	„	1,669
1823	259,633	7,508	267,034	{British, and imported from Newfoundland, 1d. each, but suspended until 5th July, 1824.	{Taken in Foreign Fishery by persons not being British Subjects, 1s. 6d. each. }	1,148
1824	336,143	17,740	322,855	„	3s. 6d.	3,952
1825	317,833	17,644	305,844	„	1s.	2,873
1826	393,566	18,822	356,686	„	„	2,961
1827	463,739	35,174	457,825	„	„	3,835
1828	297,928	8,049	289,662	„	„	2,532
1829	289,541	25,255	262,446	„	„	2,167
1830	447,215	20,183	424,518	„	„	2,900
1831	541,692	41,211	528,206	„	„	2,542

Sheep Undressed.						
	Number.	Number.	Number.	Per dozen.		£.
1820	55,210	609	59,712	2s. 3d.		547
1821	65,198	....	65,186	„		610
1822	154,444	....	153,641	„		1,440
1823	206,195	315	201,166	„		1,885
1824	52,788	2,169	56,713	„		525
1825	81,907	240	81,240	1s		413
1826	116,773	318	108,859	„		454
1827	231,498	1,260	227,140	„		946
1828	194,736	4,666	194,559	„		820
1829	83,044	375	83,200	„		350
1830	113,235	1,669	109,706	„		459
1831	116,348	13,435	90,635	„		411

Manufactures.

WORKS OF PUBLIC AND DOMESTIC UTILITY.

*Gas Works.*Gas Works
their im-
portance.

(802.) Next to the application of steam power to navigation, the discovery of the illuminating power of gas at a distance from its point of generation is the most important and interesting made in modern times; and will claim therefore particular attention. A very little more than one hundred years back, the streets of London were in the night involved in almost total darkness. At that time, the inhabitants in the larger streets were, by the Lord Mayor, ordered to hang out lanterns, giving just sufficient light to render the darkness more visible, and even these were all extinguished at about eleven o'clock. After this, the system of glass lamps furnished with oil began to be more generally adopted, not only in London, but in the larger towns in the Country, and Acts of Parliament were granted to different parishes, authorizing the overseers or commissioners to defray the expense of the same by a general rate. The lights, however, were still very sparingly distributed, with single wicks, miserable in appearance and nearly useless in effect. Afterwards, the wick was enlarged, double and triple lights were introduced, and the number greatly multiplied, so that something like a night illumination was produced; still great indeed was the step from this best mode of lighting with oil, and that which is now obtained by gas, which has made the streets of London, and of all the larger and indeed the minor towns in the Kingdom, nearly as light by night as by day.

We have above spoken of this as the discovery of the means of illuminating by gas at a distance from its point of generation, and it is in this, and not in the illumination itself, that the discovery consists; for a little consideration will show us that these very gases have at all times been the real materials from which artificial light has been obtained. The light from a blazing coal fire, what is it but the result of the combustion of coal-gas? while that from a burning lamp or candle is nothing more than the combustion of oil-gas. The essential difference between gas light and that from other combustible substances is merely in the manipulation or process, and the interposition of an interval between the production of the gas and the consumption of it. This will be evident if we attend to the succession of events which take place during the burning of a common candle. The solid oil is first melted by the heat of the flame, the fluid then rises up the wick by capillary attraction, gets more and more hot as it approaches the flame, till it has acquired a temperature capable of destroying that particular mode of combination of its elements which forms oil, and of producing therefrom new compounds, one or two of which are inflammable gases. These gases, in proportion as they are formed, take fire and burn with flame, because, at the very instant of their formation, they are both at a high temperature and in contact with atmospheric air. Now, if the oil, while decomposing, is excluded from the air, combustion will not take place; and the inflammable gases resulting from the decomposition of the oil may be collected by a proper apparatus and stored up for future use. So, in the same manner, if a piece of coal is laid upon a clear burning fire, it soon acquires a temperature sufficient for its decomposition, several inflammable gases are produced which burn in jets of white light as they issue from the coal into the air, or may be collected without

undergoing combustion by an apparatus that shall exclude the air. Mechanical Processes.

The only very obvious way of so decomposing oil or coal, that the inflammable products of such decomposition shall not be burned, is by heating them in close vessels; but in so doing, not only inflammable gas is produced, but so also are various other substances which do not make their appearance when oil or coal is burned in the open air. These substances detract from the purity of the gas, diminishing its combustibility, or occasioning a disagreeable odour, and therefore render it necessary to have recourse to various processes in order to separate them from the gas before it is made use of.

Thus, it appears, the manufacture of gas for illumination requires the use of close vessels, and likewise of some process of purification, and it is the construction of such vessels, and the methods of applying them to the purposes in question, which necessarily constitute the elements of this invention.

(803.) *History of lighting by coal gas.*—Notwithstanding the very recent adoption of this beautiful invention, some doubt exists as to the person to whom the honour of the discovery is due; indeed this, like most other important inventions, has been occasionally touched upon, and isolated properties brought to light, which for want of connection have been suffered to fall again into oblivion, till at length, when the connection is discovered, one puts in a claim for some particular author or experimenter, and another for a second, and so on, till at length the statement, instead of being clear and intelligible, is complicated and confused by claims, many of which have a very remote connection, if any, with the subject under discussion. This is the case with the history of gas lighting; we hope, however, the following brief statement will point out most of the principal steps without prejudice or partiality. History of gas lighting.

In the first place it may be observed, that the history of this discovery or invention may be divided into two branches: viz. the discovery of the inflammability of the gas obtained from coal, and, secondly, the invention of proper means of separating this gas from the other component parts, and applying it to useful purposes of utility and economy.

(804.) That coal contained such a gas has been known for many years, probably long before we have any record of such observations, but even these may be traced back as far as the year 1667, when Thomas Shirley, Esq., communicated to the Royal Society an account of a well and earth in Lancashire taking fire on the approach of a candle. This account, which is very short, may be interesting to the reader; we give it in the author's own words: Coal gas first described, in 1667, by Shirley.

"About the latter end of February, 1659, returning from a journey to my house in Wigan, I was entertained with the relation of an odd spring situated in one Mr. Hawkley's grounds, (if I mistake not,) about a mile from the town, in that road which leads to Warrington and Chester.

"The people of this town did affirm, that the water of this spring did burn like oyle; into which error they suffered themselves to fall for want of due examination of the following particulars:

"For when I came to the said spring, (being five or six in company together,) and applied a lighted candle to the surface of the water, 'tis true there was suddenly a large flame produced which burnt vigorously; at the sight of which they began to laugh at me for denying what they had positively asserted. But I, who did not

Manufac-
tures.

think myself confuted by laughter grounded upon inadvertency, began to examine what I saw; and observing that this spring had its eruption at the foot of a tree growing on the top of a neighbouring bank, the water of which filled a ditch that was there, and covered the burning place lately mentioned; I then applied a lighted candle to divers parts of the water contained in the said ditch, and found, as I expected, that upon a touch of the candle and the water the flame was extinct.

"Again having taken up a dish full of water at the flaming place, and held the lighted candle to it, it went out. Yet I observed that the water at the burning place did boyle, and heave like water in a pot upon the fire, though my hand put into it perceived it not so much as warm.

"This boiling I conceived to proceed from the eruption of some bituminous or sulphureous fumes, considering this place was not above thirty or forty yards distant from the mouth of a coal-pit there. And indeed Wigan, Ashton, and the whole country for many miles' compass, is underlaid with coal. Then, applying my hand to the surface of the burning place of the water, I found a strong breath, as it were a wind, to bear against my hand.

"Then I caused a dam to be made, and thereby hindering the recourse of fresh water to the burning place, I caused that which was already there to be drained away; and then applying the burning candle to the surface of the dry earth at the same point where the water burned before, the fumes took fire and burned very bright and vigorous. The cone of the flame ascended a foot and a half from the superficies of the earth. The basis of it was the compass of a man's hat about the brim. I then caused a bucket full of water to be poured on the fire, by which it was presently quenched, as well as my companions' laughter was stopped, who began to think the water did not burn.

"I did not perceive the flame to be discoloured, like that of sulphureous bodies, nor to have any manifest scent with it. The fumes when they broke out of the earth, and prest against my hand, were not, to my best remembrance, at all hot."

There can be little doubt but that the "bright and vigorous flame" which the writer describes proceeded from what we now call carburetted hydrogen gas.

Another communication relative to the inflammability of coal gas was made to the Royal Society in 1733, by Sir James Lowther; and another by Dr. Clayton, in 1739, but which, from other circumstances, appears to have been written some years before, being an extract from a letter without date, addressed to Mr. Boyle, who died in 1691. The following extracts from these Papers are highly interesting, and, being intimately connected with the present subject, we make no apologies for placing them before our readers, as they are given in the *Abridgment of the Philosophical Transactions* by Dr. Hutton.

Spontaneous
combustion,
1733.

(805.) "Sir James Lowther having occasion to sink a pit very near the full sea-mark, for draining one of his principal collieries near Whitehaven, in the County of Cumberland, which it was known would be near eighty fathoms in depth to the best seam of coals, which is three yards thick, the work was carried on day and night very successfully, through several beds of hard stone, coal, and other minerals, till the pit was sunk down forty-two fathoms from the surface, where they came to a bed of black stone about six inches thick, very full of joists, or open clefts, which divided the stones into pieces

of six inches square, the sides being all spangled with sulphur, and in colour like gold. Under this black stone lies a bed of coal two feet thick. When the workmen first pricked the black stone bed, which was on the rise side of the pit, it afforded very little water, contrary to what was expected; but instead of it a vast quantity of damp corrupted air, which bubbled through a quantity of water, then spread over that part of the pit, and made a great hissing noise; at which the workmen being somewhat surprised held a candle towards it, and it immediately took fire on the surface of the water, and burned very fiercely, the flame being about half a yard in diameter and near two yards high, which frightened the workmen, so that they took the rope and went up the pit, having first extinguished the flame, by beating it out with their hats. The steward of the Works, being informed of it, went down the pit with one of the men, and, holding a candle to the same place, it immediately took fire again, as before, and burnt about the same size, the flame being blue at the bottom and more white towards the top. They suffered it to burn near half an hour, and no water being drawn in that time, it rose and covered the bottom of the pit near a yard deep, but that very little abated the violence or bulk of the flame, it still continuing to burn on the surface of the water. They then extinguished the flame as before, and opened the black stone bed near two feet broad, that a greater quantity of air might issue forth, and then fired it again; it burned a full yard in diameter, and about three yards high, which soon heated the pit to so great a degree, that the men were in danger of being stifled, and so were as expeditious as possible in extinguishing the flame, which was then too strong to be beaten out with their hats; but with the assistance of a spout of water, of four inches diameter, let down from a cistern above, they happily got it extinguished without further harm. After this, no candles were suffered to come near it, till the pit was sunk down quite through the bed of black stone, and the two feet coal underneath it, and all that part of the pit, for four or five feet high, was framed quite round, and very close jointed, so as to repel the damp air, which nevertheless, it was apprehended, would break out in some other adjoining part, unless it was carried quite off as soon as produced out of the clefts of the stone, for which end, a small hollow was left behind the framing, to collect all the damp air into one side of the pit, where a tube of about two inches square was closely fixed, one end of it in the hollow behind the framing, and the other carried up into the open air, four yards above the top of the pit; and through this tube the said damp air has ever since discharged itself, without being sensibly diminished in its strength, or lessened in its quantity, since it was first opened, which was two years and nine months before. It is just the same in Summer as in Winter, and will fill a large bladder in a few seconds, by placing a funnel at the top of the tube, with the small end of it put into the neck of the bladder, and kept close with one's hand.

"The air, thus enclosed in the bladder and tied close, may be carried away and kept some days, and, being afterwards pressed gently through a small pipe into the flame of a candle, will take fire and burn at the end of the pipe as long as the bladder is gently pressed to feed the flame; and when taken from the candle, after it is so lighted, it will continue burning till there is no more air left in the bladder to supply the flame.

"The air when it comes out at the top of the tube is

Mechanical
Processes.

Manufactures.

as cold as frosty air. It is to be observed that this sort of vapour, or damp air, will not take fire except by flame; sparks do not affect it, and for that reason it is frequent to use flint and steel in places affected with this sort of damp, which will give a glimmering light, that is a great help to the workmen in difficult cases.

"After the damp air was carried up in a tube, in the manner above described, the pit was no more annoyed with it, but was sunk down very successfully through the several beds of stone and coal, without any other accident or interruption, till it came to the main seam of coals, which is 3 yards thick, and 79 fathoms deep from the surface; and the said pit being oval, viz. 10 feet one way and 8 the other, it serves both for draining the water by a fire engine, and also for raising the coals."

Dr. Clayton's discovery, communicated 1739.

(806.) *Dr. Clayton's Memoir, from the Abridgment of the Philosophical Transactions, 1739.*—"Mention is here made of a ditch, two miles from Wigan in Lancashire, the water in which would seemingly burn like brandy, the flame being so fierce that several strangers boiled eggs over it; the neighbouring people indeed affirmed, that about thirty years before it would have boiled a piece of beef; and that whereas much rain formerly made it burn much fiercer, now after rain it would scarcely burn at all. It was after a long-continued season of rain that Dr. C. went to see the place and make some experiments, when he found that a lighted paper, though it were waved all over the ditch, would not set the water on fire. He then had a dam made in the ditch, and the water thrown out, to try whether the steam which arose from the ditch would then take fire, but he found it would not. He still, however, pursued his experiment, and caused it to be dug deeper; when at the depth of about half a yard he found a shelly coal, and the candle being then put down into the hole, the air caught fire and continued burning.

"Dr. C. observed that there had formerly been coal pits in the same close of ground; and, having got some coal from one of the nearest pits, he distilled it in a retort in an open fire. At first there came over only phlegm, afterward a black oil, and then also a spirit arose, which he could no ways condense, but it forced the luting or broke the glasses. On one occasion when it had forced the lute, coming close to it, to try to repair it, he observed that the spirit which issued out caught fire at the flame of the candle, and continued burning with violence as it issued out in a stream, which he blew out and lighted again, alternately, for several times. He then tried to save some of this spirit; taking a turbinated receiver, and putting a candle to the pipe of the receiver while the spirit rose, he observed that it caught flame, and continued burning at the end of the pipe, though you could not discern what fed the flame; he then blew it out, and lighted it again several times, after which he fitted a bladder, flatted and void of air, to the pipe of the receiver. The oil and phlegm descended into the receiver, but the spirit still ascended and blew up the bladder. He then filled a good many bladders with it, and might have filled an inconceivable number more, for the spirit continued to rise for several hours, and filled the bladders almost as fast as a man could have blown them with his mouth; and yet the quantity of coals he distilled was inconsiderable.

"He kept this spirit in the bladders a considerable time, and endeavoured several ways to condense it, but in vain. And when he wished to amuse his friends, he would take one of these bladders and, pricking a hole

with a pin, and compressing gently the bladder near the flame of a candle till it once took fire, it would then continue flaming till all the spirit was compressed out of the bladder.

"But then he found that this spirit must be kept in good thick bladders, as in those of an ox, or the like; for if he filled calves' bladders with it, it would lose its inflammability in twenty-four hours, though the bladder became not at all relaxed."

(807.) Another communication was made to the Royal Society by Dr. Brownrigg in 1746, in which was described a method he had adopted in his laboratory for procuring a perpetual flame for chemical uses, by conveying from an adjacent coal pit a constant stream of inflammable gas through a leaden pipe. This was not, however, published for more than twenty years after, the author having had in view at the time a large Work on Chemistry, and at his request the communication was not published in the *Transactions*.

(808.) Notwithstanding this contrivance, it may be said that up to this time the discoveries that had been made were rather accidental than as results drawn from scientific views and investigations. But in 1767 Dr. Watson, afterwards Bishop of Landaff, undertook an examination of the properties of the component parts of coal, and he published the result of his researches in the second volume of his *Chemical Essays*. His experiments show that he examined the products arising from the distillation of pit coal with great care; and he has described them with his usual exactness. In his process he permitted the gas to ascend through curved tubes, and he particularly notices its great inflammability, as well as elasticity; he also observed, that it retained the former property after it had passed through a great quantity of water. After detailing a variety of interesting facts and calculations, respecting the quantities of coke, tar, &c., produced from various kinds of coal, he gave several useful queries to excite others to investigate the subject with a view to further discoveries. From his habit of acute and vigilant observation, and his general endeavours to render his experiments subservient to utility in the Arts, it may, perhaps, excite some surprise that the uses to which the inflammability of the coal gas was applicable should not have suggested themselves to his penetrating mind. But as the voyager, when in the search of unknown regions, has often approached very near to an interesting point, without having had the felicity to discover it; so has it occurred to the scientific explorer of nature in his diversified excursions among her unfrequented recesses. Indeed, how numerous are the discoveries which have resulted from experiments made rather with a view to private amusement than in the serious pursuit of any important object! Yet many of these have occasionally been productive of momentous consequences to mankind; and how remarkably has this proved to be the case with regard to the uses and application of coal gas!—Matthews's *History*.

(809.) Soon after this time, the late Earl of Dundonald took out a patent for distilling coals, and obtained therefrom coke and tar, the process in all its essential particulars being the same that had been largely practised at Liege, about the year 1740. Lord Dundonald's plan was for a time carried on very extensively at Colebrook Dale in Shropshire, and remnants of his Works were to be seen there some years back. The collection and employment of the gas produced by the distillation of the coal formed no part of the patentee's plan; the gas, therefore, was

Mechanical Processes.

Dr. Brownrigg, 1746.

Dr. Watson's researches.

Earl of Dundonald's patent for distilling coal.

Manufac-
tures.

suffered to escape into the air, and sometimes from curiosity, and sometimes to avoid the stench of the gas, it was set fire to as it issued from the waste pipe of the apparatus.

Up to this period, therefore, no attempts appear to have been made to apply the inflammable gas from coal to the purposes of artificial illumination as a substitute for candles, or for oil lamps, and it is here, therefore, that commences the second period of the history, when means were devised for applying the gas to purposes of utility.

Artificial
gas light
ing at-
tempted by
Murdoch
in 1792.

(810.) In 1792 Mr. Murdoch, being then resident at Redruth in Cornwall, instituted a series of experiments on coal, the object of which was, to apply the inflammable gas, obtainable from this substance by distillation, to economical purposes. The apparatus employed by him on this occasion consisted of an iron retort, with metallic tubes turned on the inside, through which the gas was conveyed to a considerable distance. At the end of the pipe, and in various intermediate places, were perforations of different sizes and forms, where the gas was set fire to. He also made trial of different kinds of coal for the purpose of ascertaining which gave the greatest quantity of gas, and of the best quality. He likewise attempted to purify the gas by washing it in water, and by other means.

Soho manufac-
tory illu-
minated in
1802.

In the year 1798, he removed from Cornwall to Messrs. Boulton and Watt's foundry at Soho near Birmingham; where he resumed his experiments on a larger scale, having for many successive nights lighted the principal building in this establishment with coal gas, and practised various new methods of purifying it; and, in 1802, the whole front of the Soho manufactory was brilliantly illuminated with coal gas on account of the General Peace.

With these well-established facts before us, it seems impossible to deny to Mr. Murdoch the principal merit of the invention. It is certain that Dr. Clayton, fifty years before Mr. Murdoch, had proved the inflammable nature of the gas, and the same fact was known from the experiments of Lord Dundonald; but in the hands of one it was only an interesting philosophical experiment, and in the other a casual result of other experiments, and although it ought, perhaps, it does not appear to have suggested the idea of applying the gas thus produced to the economical purposes of illumination.

Great
progress in
the Art,
1808.
Mr. Mur-
doch re-
ceives the
Rumford
medal,
Royal So-
ciety, 1809.

Between the term at which we have now arrived, 1802 and 1808, great progress was made in the application of gas by Mr. Murdoch and others, which will be referred to as we proceed, but we think this the best place for introducing an abstract from Mr. Murdoch's Paper, presented in the latter year to the Royal Society, in which the successive steps of his proceedings are clearly and distinctly detailed, particularly with reference to the lighting of Mr. Lee's manufactory, which was first commenced in 1805. The author states, as we have before done, that at the time of making the communication sixteen years had elapsed since, in a course of experiments he was making at Redruth in Cornwall, upon the quantity and quality of gases produced by distillation from different minerals and vegetable substances, he was induced, by some observations he had previously made upon the burning of coal, to try the combustible properties of the gases produced from it, as well as from peat, wood, and other inflammable substances, and being struck with the great quantities of gas they afforded, as well as with the brilliancy of the light and the facility of its production, he instituted several experiments with

a view of ascertaining the cost at which it might be obtained, compared with that of equal quantities of light yielded by oils and tallow.

Mechanical
Processes.

"My apparatus," the author observes, "consisted of an iron retort, with tinned copper and iron tubes, through which the gas was conducted to a considerable distance; and there, as well as at intermediate points, was burned through apertures of varied forms and dimensions. The experiments were made upon coal of different qualities, which I procured from distant parts of the Kingdom, for the purpose of ascertaining which would give the most economical results. The gas was also washed with water, and other means were employed to purify it.

Abstract
from Mr.
Murdoch's
Memoir.

"In the year 1798, I removed from Cornwall to Messrs. Boulton, Watt, and Co.'s Works for the manufactory of Steam Engines, at the Soho foundry, and there I constructed an apparatus upon a larger scale, which, during many successive nights, was applied to the lighting of their principal building, and various new methods were practised of washing and purifying the gas.

"These experiments were continued, with some interruptions, until the Peace of 1802, when a public display of this light was made by me in the illumination of Mr. Boulton's manufactory at Soho, upon that occasion.

"Since that period, I have, under the sanction of Messrs. Boulton, Watt, and Co., extended the apparatus at Soho foundry, so as to give light to all the principal shops, where it is in regular use, to the exclusion of other artificial light; but I have preferred, in the following statement, giving the results from Messrs. Phillips and Lee's apparatus, both on account of its greater extent, and the greater uniformity of the lights, which rendered the comparison with candles less difficult.

"At the time I commenced my experiments, I was certainly unacquainted with the circumstance of the gas from coal having been observed by others to be capable of combustion; but I am since informed, that the current of gas escaping from Lord Dundonald's tar ovens had been frequently fired; and I find that Dr. Clayton, in a Paper in volume xli. of the *Transactions of the Royal Society*, so long ago as the year 1739, gave an account of some observations and experiments made by him, which clearly manifest his knowledge of the inflammable property of the gas, which he denominates 'the spirit of coals;' but the idea of applying it as an economical substitute for oils and tallow does not appear to have occurred to this gentleman, and I believe I may, without presuming too much, claim both the first idea of applying, and the first actual application, of this gas to economical purposes."

(811.) We see no just cause for objecting to this claim of Mr. Murdoch. At all events, the question seems to be within a narrow compass, that is, between Mr. Murdoch and M. Le Bon, a French engineer. Mr. Murdoch's first public exhibition was in 1802; but some years previously he had informed Mr. Watt of his experiments, and, according to the evidence of the latter before a Committee of the House of Commons, he had proposed to him to take out a patent for the invention in either 1795 or 1798. Now M. Le Bon, it appears, had actually exhibited his thermo lamp in 1801, and it was known in England that he had done so. The exhibition, therefore, of Mr. Murdoch at Soho would not of itself establish his priority, but there appears no question that he had already been engaged in the pursuit for some years; for seven at least, according to the evidence of

Claims of
M. Le Bon.

Manufac-
tures.

Mr. Watt, and, according to his own statement, for ten years; and, therefore, the only question seems to be, when did M. Le Bon commence operations? Mr. Winsor's claim to the invention appears to be quite out of the question, whatever merit may be due to him for the energy with which he pursued the subject, and urged it upon the attention of the Public.

In another part of his Paper the author describes the application of his invention at Messrs. Philips and Lee's establishment, above referred to, which it will be best to give in the Author's own words.

Gas works
of Messrs.
Philips and
Lee, Man-
chester.

(812.) "It is not my intention in the present Paper to enter into a particular description of the apparatus employed for producing the gas; but I may observe generally, that the coal is distilled in large iron retorts, which during the winter season are kept constantly at work, except during the intervals of charging, and that the gas, as it rises from them, is conveyed by iron pipes into large reservoirs or gasometers, where it is washed and purified, previous to its being conveyed through other pipes, called mains, to the mill. These mains branch off into a variety of ramifications, (forming a total length of several miles,) and diminish in size, as the quantity of gas required to be passed through them becomes less. The burners, where the gas is consumed, are connected with the above mains by short tubes, each of which is furnished with a cock to regulate the admission of the gas to each burner, and to shut it totally off when requisite. This latter operation may likewise be instantaneously performed, throughout the whole of the burners in each room, by turning a cock, with which each main is provided, near its entrance into the room.

"The burners are of two kinds: the one is upon the principle of the Argand lamp, and resembles it in appearance; the other is a small curved tube, with a conical end, having three circular apertures or perforations of about a thirtieth of an inch in diameter, one at the point of the cone, and two lateral ones, through which the gas issues, forming three divergent jets of flame, somewhat like a *fleur-de-lis*. The shape and general appearance of this tube have procured it among the workmen the name of the cockspur burner.

"The number of burners employed in all the buildings amounts to 271 Argands and 633 cockspurs; each of the former giving a light equal to that of four candles of the description above mentioned, and each of the latter a light equal to two and a quarter of the same candles, making therefore the total of the gas-light a little more than equal to that of 2500 candles. When thus regulated the whole of the above burners require an hourly supply of 1250 cubic feet of the gas produced from cannel coal; the superior quantity and quality of gas produced from that material having given it a decided preference in this situation over every other coal, notwithstanding its higher price.

"The time during which the gas-light is used may, upon an average of the whole year, be stated at least at two hours per day of twenty-four hours. In some mills, where there is over-work, it will be three hours, and in the few where night-work is still continued, nearly twelve hours. But taking two hours per day as the common average throughout the year, the consumption in Messrs. Philips and Lee's mill will be $1250 \times 2 = 2500$ cubic feet of gas per day, to produce which 7 hundred weight of cannel coal is required in the retort. The price of the best Wigan cannel (the sort used) is $13\frac{1}{2}d$ per hundred weight, ($22s. 6d$ per ton,) delivered

at the mill, or say about 8s. for the 7 hundred weight. Multiplying by the number of working days in the year, (313,) the annual consumption of cannel coal will be 110 tons, and its cost £125.

Mechanical
Processes.

"About one-third of the above quantity, or say 40 tons, of good common coal, value 10s. per ton, is required for fuel to heat the retorts; the annual amount of which is £20.

"The 110 tons of cannel coal, when distilled, produce about 70 tons of good coke, which is sold upon the spot at 1s. 4d. per hundred weight, and will therefore amount annually to the sum of £93.

"The quantity of tar produced from each ton of cannel coal is from 11 to 12 ale gallons, making a total annual produce of about 1250 ale gallons, which not having been yet sold I cannot determine its value; but whenever it comes to be manufactured in large quantities, it cannot be such as materially to influence the economical statement, unless indeed new applications of it should be discovered.

"The quantity of aqueous fluid which came over in the course of the observations which I am now giving an account of was not exactly ascertained, from some springs having got into the reservoir; and as it has not been yet applied to any useful purpose I may omit further notice of it in this statement.

"The interest of the capital expended in the necessary apparatus and buildings, together with what is considered as an ample allowance for wear and tear, is stated by Mr. Lee at about £550 per annum, in which some allowance is made for this apparatus being made upon a scale adequate to the supply of a still greater quantity of light than he has occasion to make use of.

"He is of opinion that the cost of attendance upon candles would be as much, if not more, than upon the gas apparatus, so that in forming the comparison nothing need be stated upon that score, on either side.

"The economical statement for one year then stands thus:

"Cost of 110 tons of cannel coal	£125
"Ditto of 40 tons of common ditto	20
	145
"Deduct the value of 70 tons of coke	93
"The annual expenditure in coal, after deducting the value of the coke, and without allowing any thing for the tar, is therefore	52
"And the interest of capital, of wear and tear of apparatus	550
"making the total expense of the gas apparatus about	£600 per annum.

"That of candles to give the same light would be about £2000. For each candle consuming at the rate of 4-tenths of an ounce of tallow per hour, the 2500 candles, burning upon an average of the year two hours per day, would, at 1s. per pound, the present price, amount to nearly the sum of money above mentioned.

"If the comparison were made upon an average of three hours per day, the advantage would be still more in favour of the gas-light; the interest of the capital and wear and tear of the apparatus continuing nearly the same as in the former case; thus,

" $1250 \times 3 = 3750$ cubic feet of gas per day, which would be produced by $10\frac{3}{4}$ hundred weight of cannel coals; this, multiplied by the number of working days,

Manufactures. gives 168 tons per annum, which, valued as before, amounts to £188
 " And 60 tons of common coal for burning under the retorts will amount to 30

218
 " Deduct 150 tons of coke at 26s. 8d. 140

" Leaving the expenditure in coal, after deduction of the coke, and without allowance for the tar, at 78

" Adding to which the interest and wear and tear of apparatus, as before, the total annual cost will not be more than £650, whilst that of tallow, rated as before, will be £3000.

" It will readily occur, that the greater number of hours the gas is burnt, the greater will be its comparative economy, although in extending it beyond three hours an increase of some parts of the apparatus would be necessary.

" If the economical comparison were made with oils, the advantages would be less than with tallow.

" The introduction of this species of light into the establishment of Messrs. Philips and Lee has been gradual, beginning, in the year 1805, with two rooms of the mill, the counting-houses, and Mr. Lee's dwelling-house. After which it was extended through the whole manufactory, as expeditiously as the apparatus could be prepared.

" At first some inconvenience was experienced from the smell of the unconsumed or imperfectly purified gas, which may in a great measure be attributed to the introduction of successive improvements in the construction of the apparatus as the work proceeded. But since its completion, and since the persons to whose care it is confided have become familiar with its management, this inconvenience has been obviated, not only in the mill, but also in Mr. Lee's house, which is most brilliantly illuminated with it, to the exclusion of every other species of artificial light.

" The peculiar softness and clearness of this light, with its almost unvarying intensity, have brought it into great favour with the work-people. And its being free from the inconvenience and danger resulting from the sparks and frequent snuffing of candles is a circumstance of material importance, as tending to diminish the hazard of fire, to which cotton-mills are known to be much exposed."

M. Le Bon's thermo-lamp.

(813.) Such was the state to which Mr. Murdoch had brought the application of coal gas in the course of the 16 years between 1792 and 1808, but from about 1802 to the same period, 1808, other ingenious individuals had pursued the same object, and it remains for us to state what had been the result of their experiments during the latter six years. It has been stated that a grand display of this light was made in 1802; Mr. Murdoch was at that time very desirous that Mr. Watt should take out a patent for the invention, but it was thought that the circumstance of Lord Dundonald having fired the gas at his Works, as already described, would interfere with any patent right. In the same year, 1802, Mr. Gregory Watt visited Paris, and there he found M. Le Bon, a French engineer, who had already, the year before, lighted up his house and gardens in Paris with gas obtained from wood and coal, and contemplated lighting up in the same manner some of the streets of that metropolis. The name which M. Le Bon gave to his furnace or apparatus was a Thermo-lamp.

This not only attracted the notice of the Parisians, but of foreigners, and amongst others Mr. Winsor; in consequence, the latter gentleman (as he informs us in his first pamphlet) made a journey from Frankfort to Paris, for the purpose of investigating the matter more minutely. He was not, however, allowed to see any part of the apparatus of M. Le Bon, except a small oven, and failed also in an attempt to make some arrangement with him for proceeding to England, and engaging in the manufacture of tar from English coal. Thus baffled, Mr. Winsor made experiments on his own account, and his first successful result was exhibited in the Autumn of 1802, at Brunswick, in the presence of the reigning Duke and other persons of distinction. This success induced Mr. Winsor to style himself, in the title page of his pamphlet, "Second inventor and improver," being, no doubt, at that time, ignorant of what had already been done at Birmingham by Mr. Murdoch.

(814.) In 1803 Mr. Winsor began his public exhibitions at the Lyceum theatre, in London, of coal-gas illumination, and in 1804 took out a patent for his invention.

The beauty of gas-light, as compared with that from common oil lamps, and the facility with which, by means of a proper arrangement of tubes and burners, it may be made to represent any fanciful or decorative figure, strongly attracted the attention of the Public to Mr. Winsor's exhibition. The earnest zeal and enthusiasm of the patentee likewise concurred powerfully to the same end; and, notwithstanding some very obvious and stupendous exaggerations in his estimate of the expected profits of the scheme, he soon acquired friends and supporters who enabled him, in the Spring of 1807, to light up a part of the south side of Pall Mall with coal gas, and thus demonstrate the practicability of his plan.

The jet and burners used in Mr. Winsor's exhibition, at the Lyceum, were nearly the same as those at present employed, but, as was natural to expect in a first and comparatively rude attempt, leaks were frequently occurring in the pipes, through which the gas escaped and annoyed his audience, and the gas even when burned produced unpleasant sulphureous exhalations, which were the subject of much complaint. To remedy this, the gas in its progress from the retort to the gasometer was passed through perforated plates at the bottom of a cistern of lime water, and afterwards milk of lime was substituted for the lime water with manifest advantage, the application of this liquor to the purification of gas being, it is believed, an original invention of Mr. Winsor.

In 1809, Mr. Winsor and his friends applied to Parliament for an Act of Incorporation, with liberty to raise a capital of £200,000; the application, however, was not successful, partly in consequence of Mr. Murdoch's opposition, who brought forward, apparently to the satisfaction of the Parliamentary Committee, his proofs of priority of discovery. The application, however, was renewed in the next year: though it encountered some opposition, and incurred considerable expense, yet the parties succeeded in obtaining an Act to authorize his Majesty to grant them a charter, within three years from the time of passing the Act. But the Bill, as originally introduced, was materially altered, and certain conditions were imposed, which limited their powers to London, Westminster, Southwark, and the suburbs adjacent. Besides, it was stipulated, that, if required, they should contract with the parishes of London, Westminster, and Southwark, to furnish a stronger and better light, and

Mechanical Processes.
 Mr. Winsor's propositions for a National Gas Company.

Applications to Parliament.

Manufactures.

at a cheaper and lower price, all expenses included, than such parishes could be supplied with oil, if lighted in the usual manner. Their capital was limited to £200,000, which was to be raised in shares of £50 each; they were not authorized to exercise any of the powers granted by the Act till such time as £100,000 were subscribed; and the Act also obliged them to raise the full sum of £200,000 within three years from the time the charter should be granted. For managing the affairs of the corporation, a governor, a deputy-governor, and ten directors were to be elected; and holders of two shares, and less than four, to have one vote; four and less than eight, two; eight and less than sixteen, three; sixteen and less than twenty-four, four; and twenty-four and upwards, five votes; and no person was to be entitled to vote unless he had held two shares, and had possessed them for six calendar months. A variety of minuter conditions were included respecting general Meetings, dividends, &c., which it is unnecessary to detail, but such is a general outline of the Act. Thus, by perseverance, the persons who had engaged in this great speculation succeeded in the attainment of the leading point which they had so anxiously sought; and Mr. Winsor's plan of a National Light and Heat Company was in part accomplished, by the legal formation of a local Gas-light and Coke Company.

Whatever reflections were made at the time the subject was so much agitated, it must be admitted that the zealous and unremitted exertions of the individuals engaged in this arduous business have been productive of very important consequences; but the advantages resulting from their success have proved beneficial to the Public in a much greater proportion than to the original projectors, or the present proprietors. From the extent to which gas-lighting has since been applied, if Mr. Winsor could have unquestionably shown his just right to a patent for the discovery, the pecuniary benefit he might have derived from it would have been very considerable; but, whatever praise may be due to him for attracting attention to the subject, it is now generally allowed that he was not the discoverer, and that his pretensions to be such had no foundation.

First Company incorporated.

The incorporation of this Company conduced to fixing the art of gas-lighting upon such a basis as promised its permanent establishment, and increased the probability of its ultimate success. Various and plausible as were the objections urged against it at the time, experience has proved that the property of an individual was neither adequate to the magnitude, nor likely to be risked, in such large and expensive undertakings; and this was shown by some facts adduced in the evidence to support the Bill. By calculations made from actual surveys, it appeared that the expense of laying down pipes for the city of Westminster alone would be £150,000, without including any thing else. There were also other circumstances that entitled this Company to particular attention; for, previously to this period, their experiments for making, purifying, and applying the use of coal gas to the purpose of lighting, had been made on a large and expensive scale; and although the Public had been partially benefited from the knowledge obtained by their means, hitherto no pecuniary advantage had resulted to themselves, notwithstanding their zealous exertions to improve and introduce the Art of gas-lighting. The hope of future benefits, however, animated them in their further efforts to attain their object. Perseverance enabled them to

overcome the great difficulties which attended their pursuits; the success of their endeavours has excited and encouraged others to engage in the same course and imitate their example; and how many similar Companies may trace their origin to the stimulus produced by the successful establishment of this!—Matthews's *Historical Sketch of Gas-lighting*.

(815.) Before we proceed to explain further the progress of this Art, it will be proper to introduce the name of another individual, who has perhaps contributed more largely to the practical improvement of it, and has invented more useful apparatus connected with it, than any other person whatever. In 1820 Mr. Clegg published a pamphlet with a view to claim his share in the invention of several Machines, some of which, he considered, had been unjustly pirated from him, and, without giving any opinion on this point, the following statement, as abridged from the pamphlet, by Mr. Matthews, in his valuable History, will show how largely the author contributed, in the infancy of the Art, in bringing it to its present state. His attention, he states, was first called to the subject in 1804, and in the following year he erected a gas apparatus at the cotton-mill of Henry Lodge, Esq., near Halifax, which was the first complete permanent Work of the kind in England. In 1806, the private house of the same gentleman was also lighted by him, and here he first attempted to purify the gas by lime introduced into the tank in which the gasometer floated. In 1807, he lighted the manufactory of Messrs. T. and S. Knight, of Longside, near Manchester, and, in 1809, that belonging to Mr. Harris, at Coventry, and here the paddle was employed for agitating the lime at the bottom of the tank. In 1811, he also erected a gas apparatus at Dolphinholme, near Lancaster; and, in the same year, another at Stoneyhurst College, Lancashire, where the first separate lime Machine was introduced. In the same year he lighted the mill belonging to Mr. Greenway, in Manchester, and here was the first introduction of the hydraulic main. These last two inventions have contributed very largely to the present extensive application of gas throughout the Country. In 1812, he erected two other gas Works, with some additional improvements; and, in 1813, he was chosen engineer to the Chartered Gas Company in London, and from that time the affairs of that corporation, which hitherto had to contend with great difficulties, began to revive; but, in 1813, an explosion having taken place at their Works in Westminster, the Government interfered, the question was referred to the Royal Society, who appointed a Committee to examine into the circumstances, and who made their Report in 1814, but which was not given to the Public till 1823, when a second Committee of the House of Commons was appointed to inquire into various subjects connected with gas establishments. Our limits will not allow us to give the particulars of this interesting inquiry to the extent we should have wished to have done, but the Report of the Committee, with some trifling abridgement, will itself be found very instructive and interesting.

(816.) *Report of the Select Committee of the House of Commons, appointed, in 1823, to make inquiries on various subjects connected with gas-lights, gas establishments, &c.*

"Your Committee are of opinion that the danger likely to arise from gasometers and gas Works is not so great as has been supposed, and that, therefore, the necessity of interference, by the legislative enactments

Mechanical Processes.

Mr. Clegg contributed largely to the success and perfection of gas Works.

Report of a Parliamentary Committee, 1823.

Manufac-
tures.

pointed out in the Reports referred to them, does not press at the present period of the Session.

"It appears that great improvements have taken place in the apparatus, Machinery, and management of gas Works since 1814, the date of the Report from the Committee of the Royal Society, which have very much lessened the danger of such Works; and that improvements are daily making in every department of them, which must still further lessen the danger necessarily attendant on such establishments.

"The evidence sufficiently supports the opinion that the risk of accident or danger is but small, if the ordinary care and attention necessary in every large establishment be paid by the officers and workmen employed on the premises.

"It is in evidence that the carburetted hydrogen gas usually supplied to the Public is not, of itself, explosive; but that, in order to render it so, a mixture of from five to twelve parts of atmospheric air, and the application of flame, is necessary; whilst the manner in which the gasometer houses are in general built renders it extremely difficult to form the mixture requisite for explosion, and consequently renders the chance of danger remote.

"The danger attendant on the use of gas in the streets and passages appears also to be small; and that it will, probably, by the better management and care of the persons employed in these establishments, be henceforth lessened.

"The Committee beg to refer to the evidence respecting the accidents, by explosions of gas, stated to have occurred at Edinburgh, Manchester, and other places, as to their extent.

"It appears that, in some of the gas Works, safety lamps, on Sir Humphrey Davy's plan, are used on the premises, to guard against accidents which might occur by the application of flame to any explosive mixture that may have been formed by leakage from the gasometers or pipes; and, as the Committee consider that precaution very necessary, they trust the Directors of every establishment will immediately adopt them, both for their own and the public security.

"There are several suggestions in the Reports, and in the evidence, as to the limits of districts, the size of gasometers, the distance of placing them from each other, the structure of the houses and roofs, the kind of tanks, &c., that deserve very serious attention; and, although the Committee view the interests of the gas establishments as intimately connected with the avoidance of danger from the gas, they are decidedly of opinion that such further power should be given to the Secretary of State, over all gas establishments, as shall be deemed requisite to carry into effect the improvements in the works that may be necessary for the safety of the Public.

"The Committee cannot close their Report without expressing their satisfaction that the Public have obtained so great and so rapidly increasing a means of adding to the convenience and comfort of society as the use of gas, under due management, must afford; and they are of opinion that, as a means of police, much benefit would be derived from its general introduction to light the streets of this metropolis.

"Your Committee have deemed it proper to add to their Report, by way of appendix, the examinations of the several witnesses called before them; and they beg leave to refer generally to the printed Reports of the Royal Society and of Sir William Congreve.

(817.) "Sir Humphrey Davy, Bart., President of the Royal Society, examined. Mechanical Processes.

"Have you seen the Report that was made by a Committee of the Royal Society, in the year 1814, respecting the explosion which had then lately taken place in the gas works at Peter Street, and with respect to the dangers that are liable to occur in gas Works?—I have read that Report with great attention. Evidence of Sir H. Davy.

"Do you think the estimate of the possible explosive force of a gasometer of 14,000 cubic feet is overrated, when, as stated in that Report, it is compared with an explosion of 10 barrels of gunpowder in its most favourable circumstances, and supposing the least explosive force that it is capable of?—I should conceive, certainly, it is not overrated.

"Do you conceive that the danger of explosion from the gasometer increases with the size of the gasometer?—Beyond all question; there is not more danger of explosion, but more danger from the explosion.

"The size does not make the danger, but it augments the fire when the explosion takes place?—Just so.

"Are you to be understood that you think a large gasometer as manageable as a small one?—I should suppose not; but what ingenuity can do, and what Machinery can do, is a question it is impossible for any individual to answer.

"Is it not probable that lightning might produce an explosion in a charged gasometer, by rending the gasometer at the moment that the lightning struck it?—Supposing lightning to pass through a conductor of electricity, which is highly improbable, at least in such a way as to make an aperture, it might produce combustion; I think it would not produce explosion: supposing an aperture made by lightning, by which the gas might escape, it would come out as an immense column of flame, but I think without explosion.

"If the whole contents of a large gasometer were sufficiently inflamed by lightning, or any other cause, do you not apprehend that serious mischief would be done to the neighbouring gasometers, and to the building surrounding the gasometer so struck?—I should think the roof of the building would be destroyed.

"Might not a sudden conflagration produce an extreme rarefaction and concussion that would produce the same effect, in some measure, as an explosion?—It is necessary to premise, with respect to that question, that the gas in a gasometer can only explode when mixed with at least five times its volume of air, and it will explode when mixed with ten times its volume of air; now, supposing, what appears to be an almost impossible case, of an aperture made by lightning in the upper part of the gasometer, a large aperture of two or three cubical feet, the lightning, in making that hole, would of course inflame the gas, and the pressure of the atmosphere would cause the elastic fluid to flow out as an immense column of flame; but I do not conceive the effect would be the same as that of an explosion; it would be quite a different effect. I should rather think it would not destroy the gas-holders, unless any part of the flame came in contact with the iron of the gas-holders; suppose the hole struck in the side of the gasometer, the column of flame would flow laterally, and might injure the other gasometers.

"Have you seen the gas Works in Peter Street?—I have to-day.

"There are from fourteen to fifteen gasometers, not in

Manufactures.

actual contact, but placed very near together; what do you conceive the effect of the explosion of one of the largest gasometers in Peter Street would be amongst the other gasometers in those Works?—It is extremely probable that they would be overturned, torn in pieces, removed from their situations, and the whole exploded; but it is very difficult to answer that question, because it is a matter of experimental research; and, if I wanted to ascertain whether they were likely to be exploded, I should have a model of them made on a small scale, and introduce an explosive mixture into one, and ascertain what the effect would be upon the others. I think an experiment of that kind would be more satisfactory than any opinion I can give; when we act on a great scale, the results are not always the same; when we argue from the force of gunpowder, they are not exactly the same; they are both extremely dangerous, but nobody can predict the exact result.

“Supposing one gasometer exploded, and that there were three or four in the neighbourhood, as in Peter Street, would the chance of the explosion communicating to the adjoining gasometers be as great as it would be if one barrel of gunpowder exploded among three or four other barrels of gunpowder?—Not nearly so much; the flame is less intense, the heat is less, and there is a possibility that, in the open atmosphere, a gasometer at the distance of 50 or 60 feet might not be destroyed; it would depend entirely on the force of the explosion. If a person were to make the most explosive mixture, the effect would be very different from an explosion; from a small quantity of air there would be a range of differences in intensity, from one to twenty times; if the smallest quantity of air which produces explosion happened to be in the gasometer, the explosion would be a small one; if the largest proportion, the force of the explosion would be very great.

“Do you think that, as the gas establishments are at present conducted, the chances of explosion are great?—No; very small.

“Do you think it most probable, since the year 1814, that such improvements have been introduced into the mode of fixing the gas-holders, and other improvements, that, at present, the chances of explosion are comparatively slight to what they were when this Report was made?—As I did not examine at the time, I cannot say; I have never seen any gas establishment till this morning; it appears to me, from the short examination I made, that the chances of explosion are exceedingly small; they must be so, indeed, from the length of time which has elapsed since any explosion of consequence has taken place.

“There are three chances of explosion, according to this Report; namely, in the gas-holder, after the gas is expelled from the gas-holder and introduced into the pipes, and, afterwards, in the houses where the gas is lighted?—Yes.

“Do you think it necessary, in the regulations, to guard against the explosions that may take place in the mains under the streets, or where the lamps are lighted in the different shops?—I believe the Report of the Royal Society states, that there is no chance of explosion in the pipes; that the explosion does not pass down through a pipe of that diameter.

“The question refers to leakage?—Yes, a mixture being made; I believe there have been some explosions in shops, but then they would not act to any extent, they would be only limited to a very small space.

VOL. VII.

There is one great source of advantage in the coal gas, which is the large quantity of common air it requires to be mixed with it to produce explosion. Mechanical Processes.

“A very powerful explosion may be produced by three parts of atmospheric air?—I have been able to produce in the coal gas I have made, by four parts, a very slight explosion, but eight or nine parts produced the maximum of explosion in the experiments I made.

“You have said you were generally satisfied with the Report made by the Royal Society, with the exception of the extent to which they have limited the gasometer?—My feeling was, that they had not exactly considered that part of the subject; and, perhaps, at that time it was not supposed gas establishments would be so extensive. I think it would be inconvenient to the Gas Companies to make gasometers on so small a surface; it would be more expensive. I think a gasometer, containing 12,000 cubical feet, would not be dangerous, if properly separated from other gasometers.

“In fact, you think, with proper caution, a gasometer containing 20,000 cubic feet is removed pretty well from danger?—I think so; the danger must be increased according to the size both of the object bursting and the explosion from it.

“It is not more difficult to make an explosive mixture in a large gasometer than a small one?—More difficult, certainly, by the same aperture; it would take more time; the time would be greater in proportion as the contents of the gasometers were more.

“It would take a greater length of time to create an explosive mixture in a large than a small one?—By the same aperture, certainly.

“You think there would be no explosion from lightning, but that the gas would be inflamed, and ascend in a column of flame?—I think it is almost impossible that inflammation from lightning can take place, for a gas-holder is so good a conductor, that every discharge from a cloud in the electrical state would pass down the sides of the gasometer. I see no reason why it should pass into the gasometer; it is, in my opinion, almost an impossible case.

“You just stated a reason for considering coal gas to be particularly safe; did you mean that it was more safe than any other?—There are gases which require still larger portions; oil gas, for instance.

“Do you consider oil gas preferable to coal gas?—In every respect as far as lightning is concerned.

“As far as danger is concerned?—There is less, certainly.

“Does it require a greater quantity of atmospheric air to produce an explosive mixture?—It does.

“In what proportion more, taking five parts as to coal, what should you state as to oil?—I have never made any experiments upon the subject; pure olefiant gas requires a larger proportion; it does not explode powerfully with less than eight parts; it requires six to produce a mixture which will be at all explosive.

“Then the Committee are to understand, that the danger arising from explosion in one of the large gasometers would not be proportioned to the number of cubic feet they actually contained, but to the proportion in which that is mixed with atmospheric air?—Certainly.

“Then a gas-holder, containing 20,000 cubic feet of gas, might explode without any very great danger to the neighbourhood?—It could not explode at all without danger. To make the greatest explosive effect would

Manufac-
tures.

require 18,000, or 16,000, or 17,000 cubic feet; therefore, it ought to contain above 2000 feet of gas at the time.

"In proportion to the size of the gasometer is the difficulty of inflaming that gas?—Not of inflaming, but of making an explosive mixture from the same aperture.

"Not the danger in point of facility, but in point of time; it would require a longer time?—Yes; and the effect would be much more dangerous when it took place; but there would be a greater chance of discovering a leak in consequence of the longer time required.

"If a leak were to be made in a gas-holder, and the gas, by escaping, were to mix itself with the surrounding air, would not that produce such a smell that even the least skilful of the persons in the habit of managing the gas establishments would be put upon their guard, so as to take precautions against the danger that would arise from fire being supplied?—Yes; unless the delicacy of smell, the sensibility of the olfactory nerves, were blunted by habit; which, however, I suppose is not the case.

"Would you feel yourself competent to advise this Committee as to the danger or safety of Works of such extent, without having an opportunity of visiting them in person?—Certainly not.

"You have stated, that you should feel it necessary to make certain experiments before you could pronounce positively; those experiments have not been made?—I have had no motive for making them, nor should I make them personally; but, if I required such results, I should get them made.

"Have you ever known of any accident, either by way of bursting or explosion, happening to a gasometer, or a gasometer-room?—I think I have seen in the newspapers some such accounts, but I do not recollect them with precision.

"Assuming that, since the year 1814, the gasometers had increased in number from one to forty-seven, and their contents from 14,000 cubic feet to 917,000 cubic feet, and that no explosion or bursting either of a gasometer or a gasometer-room should have taken place during that period, would not that, in your mind, afford an inference both as to the safety of their construction and the care of their management?—I suppose so. It is a question of probability; it does not appear to me to be at all of the nature of a scientific question. I have already stated that I think the probability of explosion very small.

"William Hyde Wollaston, M. D., examined.

Evidence
of Dr. Wol-
laston.

(818.) "If a gasometer were overturned by a burning roof, would not the sudden conflagration of the gas, so discharged, produce something equivalent to an explosion?—It is difficult to judge; I never saw so large a quantity fired. The name which that gas originally had, was lambent inflammable, from its tardy combustion. If you have two vessels set side by side, one of common hydrogen, the other of carburetted hydrogen or coal gas, and turn up one and set fire to it, you have an immediate explosion, from the instantaneous mixture of pure hydrogen with the common air; but if you turn up the other, and set fire to it, you have a lambent flame. It was called Lambent Inflammability, in consequence of the slowness of the combustion which takes place.

"Do you apprehend that any serious mischief might be done by lightning striking the gasometer?—I cannot conceive it at all; I cannot conceive lightning setting fire to the gas which is contained in it

"Not if it were to pierce the gasometer?—Supposing it threw down the building, all the effect of lightning must be gone before that gas can mix with common air.

"If it were to rend the gasometer, would there not be a probability of inflammation at all events?—I do not understand how the lightning itself can rend the gasometer; the gasometer being of metal, I do not see how it can be rent by it.

"If any one of those gasometers, by design or by accident, were to explode, what do you conceive would be the probable result with respect to other gasometers at no great distance from the exploded one?—It is not probable, I think, that an explosion would take place; it is much more likely that they would burn slowly, from being burst. If a sudden bursting of a gasometer took place in the presence of fire, I would not expect an explosion in consequence; I may be wrong.

"Suppose an explosive mixture to exist in one gasometer, either by accident or design, and fire put to it, what do you apprehend would be the effect on the neighbouring gasometers?—It would much depend on the relative distance of the party-wall. A strong party-wall might be thrown against an adjacent gasometer, and burst it; it is probable it would not take fire; the gas would escape; but, even if there were fire present, I should not expect any sudden explosion to take place in the neighbouring gasometer.

"You were one of the Committee of the Royal Society that signed this Report in 1814?—I was.

"In this Report I find this passage: 'The receiver is suspended and balanced in such a manner, that the water in the tank shall be kept about half an inch above the level of the water in the receiver, and this constitutes the pressure by which the gas is forced out to feed the lamps; as long as every part of this reservoir is kept in good repair, and perfectly tight, the pipes leading into and out of it maintained in proper condition, and plenty of water supplied, so that the parts which ought to be under water shall never be left bare, it seems to your Committee scarcely possible that any explosion should take place; but, under the management of an unskilful or negligent superintendent, defects might occur in different parts of the Machinery, by which the gas might come to be mixed with common air, and give rise to the most dangerous explosions.' Since the year 1819 have you had any occasion to alter this opinion?—I know that such accidents can occur, but they occur but rarely; I know but of three or four instances. These are, one which took place at Newcastle, one that took place at the Custom House, and the third at Savory and Moore's in Bond Street; there was another, I believe, under the Arcade, at the Opera House.

"Have you known of any within the last twelve months?—I do not happen to know of any one within the last twelvemonth.

"Do you know that great improvements have been made in the gas apparatuses since the period when this Report was made?—I am persuaded there must have been improvements; but I cannot say that I know of them.

"You say, that the proportion to make the greatest explosive mixture is in the ratio of nine to one?—Nine or ten to one.

"Then, in a gasometer holding 20,000 cubic feet, there could be more than 2000 cubic feet of the gas when the explosive mixture was at the highest?—Certainly.

Mechanical
Processes.

Manufac-
tures.

"Upon that occasion, granting that an explosion would take place in its greatest possible degree, the whole explosion of a gasometer holding 20,000 cubic feet would not be quite the proportion of two barrels of gunpowder?—This involves the question put before; and, upon that, I should be glad to know how many pounds there are in a barrel of gunpowder. (It was stated to the witness that it was 100 pounds net.) Then I will draw an inference from Sir William Congreve's experiment, (subject to his correction,) that if 1 cubic foot is equal to half an ounce, 3200 cubic feet of the same mixture will be required to be equal to a barrel of gunpowder; which 3200 feet appears a near coincidence with the Report of the Royal Society, stating 3000. But the proportion of the mixture, in his experiments, it appears, is different.

"Then those 3000 are 3000 cubic feet of the gas unmixed?—No; 3000 feet of the mixed gas. The experiment that seems to concur with the note in the Report, gives 3200 feet of the mixed gas, of which one-tenth would be 320 feet of coal gas, equal to a barrel of gunpowder; but it is mixed here in the proportion of one to five, instead of one-tenth.

"You are taking this from the experiment before you, and not giving it as the result of your own experiment?—Certainly; I am giving it here just as I find it.

"Do you think there is more danger and more difficulty in the management of a gas-light establishment than there is in the management of gunpowder?—Most certainly not; most certainly much less precaution is necessary against accident.

"Do not you believe that the best safety to the Public, superior to all regulations and all rules laid down by Act of Parliament or otherwise, will be in the safety of the management of their own property by those different Companies?—It appears to me that the Government may rely upon the interest of the parties to take all the precaution they can.

"In your opinion, supposing the establishments to be conducted by very skilful and attentive persons, is the danger of explosion, under such circumstances, small or great?—I presume it to be very small. It requires such a concurrence of circumstances to have an explosion take place; the admixture of a due proportion of common air with the gas, and then fire to be put to it at the proper time; there are various cases in which two circumstances are requisite, and various others in which three are requisite. I do not recollect having noted more than three; but where three conditions are requisite, the probability is so remote that I should not trouble myself to estimate the danger.

"You state that the proportion to give the strongest explosion is from nine to one?—Nine or ten to one.

"Are the Committee to understand that it has been ascertained that after that the explosion weakens?—Yes, that is what I mean to say. I understand that if the air is increased to eleven or twelve to one, the explosion is weaker and weaker. Where the explosion terminates I do not know; but this I would say, that, when the quantity of common air exceeds the due proportion, explosion is sudden, though less violent; but when the air is deficient in quantity the explosion will be slower.

"If it is explosive, will it not always be sudden?—No; there are degrees of rapidity of explosion between the proportions of ten to one and that of five to one; for instance, when the quantity of air is redundant, if the mixture fires at all, the whole goes off; but, when the

air is deficient, part of the gas fires by progressive admixture with fresh air.

Mechanical
Processes.

(819.) "John Millington, Esq., examined: a civil engineer and professor of Mechanical philosophy in the Royal Institution.

"Have you seen a Report of the Committee of the Royal Society which was laid on the table of the House of Commons?—I have. Evidence of Professor Millington.

"Do you think the calculation of the explosive force of gas, as compared with gunpowder, in that Report is overrated?—I believe it to be quite correct.

"Have you seen Dr. Young's calculation of the comparative force of gas and gunpowder?—I have not.

"Sir William Congreve stating that this was the calculation referred to in page 1 of the Report of the Committee of the Royal Society, by the words, 'A calculation of the probable force of an explosion of the gas,' was communicated by one of the Members; the same was delivered in and read as follows:

(820.) "*Estimate of the Force of Explosion of Coal Gas, laid before the Committee of the Royal Society in the year 1814, by one of its Members.*

"It must be confessed that, without direct experiments in the force of any exploding compound, we can obtain nothing more than probability by calculating from the analogy of other similar effects; but, provided that we take sufficient care not to underrate the forces in question, we may obtain from such a comparison at least a useful estimate of their greatest possible magnitude. Consequences of explosion

"Dr. Henry has found (*Phil. Trans.* 1808) that coal gas requires for its combustion about twice its bulk of oxygen gas, and affords a little more than its bulk of carbonic acid; now, since common air contains only 21 per cent. of oxygen, it can combine with no more than 12 per cent. of coal-gas; so that 112 parts of the mixture contain but 33 of substances capable of affording heat, while the remainder tends in some measure to impede their union; hence, we cannot suppose the heat thus generated to exceed about one-fourth of the heat which would be excited in the mixture of the gas with pure oxygen; and we shall probably exceed the truth in allowing to the combustion of such a mixture a heat equal to that which is evolved in the deflagration of gunpowder, which is sufficient upon the most probable estimate to increase, in the ratio of 1 to 80, the natural elasticity of the fluids generated, which amount to 250 times the bulk of the powder, so that the elasticity thus augmented becomes equal to 20,000 atmospheres. It is true that some of the solid substances contained in gunpowder may possibly be converted into vapour, and may contribute to its effect; but we have no sufficient reason to believe that the vapours of any of these substances would be more elastic than air; and Count Rumford's hypothesis, concerning the effect of steam, is every way inadmissible, since, even if nitre contained water of crystallization, its vapour would be little more effectual than an equal weight of the gaseous substances.

"We may, therefore, suppose the exploding mixture to acquire a degree of heat capable of increasing its elasticity in the ratio of 1 to 20. Dr. Ingenhouz, following Robins, makes the explosive force of a mixture of oxygen and hydrogen equal to 4 atmospheres only; but the assumption of a degree of heat equal only to that

Manufac-
tures.

which Robins obtained in a fire, is wholly arbitrary, and a single drop of ether in a bottle of oxygen appears to have exploded with a force much more than commensurate to such a cause. On the other hand, when we consider with what safety a mixture of oxygen and hydrogen may be made to explode in a common quart bottle of green glass, we cannot hesitate to allow that 80 atmospheres must be a very ample estimate of the force of explosion of a mixture of oxygen and coal-gas. As the ignited gas expands, it loses a portion of its elasticity, not only by the diminution of its density, but also by the effect of the expansion on its temperature, which may be estimated as altering the elasticity in the proportion of the biquadrate root of that of the densities. Calculating upon these grounds, we find that the whole mechanical power of an explosion of 15,000 cubic feet of a mixture of coal-gas and common air is equal to that of the explosion of 6 cubic feet, or 4 barrels of gunpowder; and if we suppose the heated gases in both cases to escape and mix with the common air in a building containing 30,000 cubic feet, so as to produce an effect commensurate to the temperature of the whole mixture, the explosion of about 15 cubic feet or 10 barrels of gunpowder would be required, in order to produce, like the gas, a force of about 10 atmospheres for the whole space. It must, however, be recollected, that gunpowder thus disposed is very unfavourably situated for producing violent effects; and that a much smaller quantity, in ordinary cases, would be more formidable than the explosion of the coal-gas. A more precise idea of the effects of such an explosion may be obtained from the calculation of its projectile effects, which would carry some parts of the wall of the surrounding building to a height of nearly 150 yards, and others to a distance of nearly 300. If the walls were in immediate contact with the gasometer, the height and distance would be twice as great; but a roof of carpentry and tiles, being lighter, would be carried higher, while the lateral force of the explosion would be diminished.

"Supposing the explosion of the gas to be unconfined, the shock would throw down a brick wall of 9 feet high and 18 inches thick, at a distance of about 50 feet from the centre; it would probably break glass windows at 150 yards, and at 300 would produce an effect similar to the instantaneous impulse of a very high wind.

"Calculation.

Calcula-
tion of the
force by Dr.
Young.

(821.) "In order to compare the whole force of expansion in a confined channel, let the length occupied initially by the gas be a ; then, when it becomes ax , the elasticity will be diminished in the ratio of 1 to $x^{\frac{5}{4}}$, and the force will be expressed by $nx^{\frac{5}{4}} - 1$, and the fluxion of half the square of the velocity by $nax^{\frac{5}{4}} - ax$; and the fluent will be $-4nax - \frac{1}{4} - ax$, which is initially $-4na - a$; and, finally, when $nx^{\frac{5}{4}} - 1 = 0$, or $x = n^{\frac{4}{5}}$ and $n = x^{\frac{5}{4}}$, $= -4ax - ax$, and the difference, showing half the square of the velocity generated, is $(4n + 1 - 5n^{\frac{4}{5}})a$. When $n = 20$, the expression becomes $26a$. When $n = 20,000$ it becomes $66,204a$; and in order to make these values equal, the latter value of a must be $\frac{1}{2540}$ of the former, whence $\frac{15,000}{2540} = 5.9$.

"In a similar manner, when a is the radius of a sphere, or of a hemisphere, which expands in every direction, the elasticity will vary as $x^{-\frac{15}{4}}$ and the fluxion will be $nax^{-\frac{15}{4}} - ax$, and the fluent $-\frac{4}{11}nax^{-\frac{11}{4}} - ax$,

which, being corrected, gives for the half square $(\frac{4}{41}n + 1 - \frac{15}{11}n^{-\frac{4}{11}})a$. The fluent thus found may be compared with the feet in which the force of gravity would produce an equal velocity, by increasing it in the ratio of the pressure of an atmosphere to the weight to be moved, that is, for a brick wall 18 inches thick, multiplying it by 11; so that when $n = 20$ and $a = 15$, $5242a = 865$ feet, the height of ascent; or, supposing the space doubled, and $n = 10$, and a about $18\frac{1}{2}$, the height would be 430 feet.

Where the explosion of the gas takes place without an obstacle, the mean force being about $\frac{5242}{2.223}$ atmo-

spheres, the velocity of expansion will be about 2000 feet in a second, or perhaps a little greater, on account of the lightness of the gas; but this excess will be compensated when the velocity is afterwards communicated to the surrounding atmosphere; with this velocity, the centre of inertia of each elementary pyramid of the sphere will advance from the distance $\frac{3}{4}$ of 15 to $\frac{3}{4}$ of 33.35 feet through $13\frac{3}{4}$ feet in $\frac{1}{145}$ of a second; and, at any greater distance d , the velocity of the impulse will be

reduced from 2000 to $2000 \frac{25}{d}$ or $\frac{50,000}{d}$, its duration

being always $\frac{1}{145}$ of a second. Thus the velocity of a very high wind, being 60 feet in a second, the impulse would retain this force at the distance of 833 feet; and in order to determine at what distance it would overset a wall 9 feet high and $1\frac{1}{2}$ thick, we must first find the height through which the centre of oscillation of the wall at $\frac{2}{3}$ of its height must ascend; and in order to be immediately over the point of support, that is,

$\sqrt{(36 + 1)} - 6 = \frac{1}{12}$ of a foot, and the velocity corresponding to this height would be generated by the force of gravity in $\sqrt{\frac{1}{193}} = \frac{1}{13.9}$ of a second: and in order

to be generated in $\frac{1}{145}$ it requires a force 10.43 times as great, or equal to the pressure of a column of brick 15.64 feet high, that is, $15.64 \times 125 = 1955$ pounds for every square foot, which is equivalent to the pressure occasioned by a velocity of 966 feet in a second, and answers to a distance of 52 feet.

"Does it not appear from the Paper, that the calculation in the *Report of the Royal Society* intends to state that it is a mixture contained in the gasometer of 15,000 cubic feet which is equal to four or five barrels of powder, not of 15,000 cubic feet of gas, but a mixture that would be contained in a gasometer of that size? —In reading the *Report of the Royal Society*, it certainly appeared very clear to me that it was mixed gas which was alluded to in the Report. In this Paper, which professes to come from Dr. Young, mixed gas is stated, and therefore there can be no doubt about it; but, at the same time, there is such a want of accordance between the two accounts given in the *Report of the*

Mechanical
Processes.

Manufac-
tures.

Royal Society and in this Paper, that I can hardly conceive how they can be supposed to refer to each other; for in the Report, near the bottom of page 4, it is said, 'As to the effect of an explosion, if it should take place, the best calculation that has been made from data not very exactly determined is, that in a reservoir containing 14,000 cubic feet, it would not, under circumstances the most favourable to the explosive force, be equal to the effect of 10 barrels of gunpowder; and on an average of all circumstances would seldom exceed that of five.' Now Dr. Young, in this Paper, says, 'Calculating upon these grounds, namely, the previous ones explained in the Paper, we find that the whole mechanical power of an explosion of 15,000 cubical feet (instead of 14,000) of the mixture of coal gas and common air is equal to an explosion of 6 cubic feet, or 4 barrels, of gunpowder,' instead of 10 or 5 as the minimum. On referring to this Paper it appears that Dr. Young's name is not to it. I beg to say, that what I stated was not in the way of objection to this calculation; it was merely as to the want of accordance in the two Papers. If I am asked, whether those gases are explosive, and can produce as injurious effects as gunpowder, I should say, Yes; and I have already said, that I do not think that the force of gas is overrated in this Paper; I think that, when it takes fire, the force of it is as great, and will do mischief as great, as gunpowder.

"You state that opinion from experiments made by yourself?—Yes.

"And not founded on the experiments of any other individual?—Upon my own, certainly; corroborated by those of others.

"You have no doubt that the interpretation of that paragraph in the Report is, that it is only a portion of the gas that would be contained in a 14,000 feet gasometer, as there designated, and not the explosion of the whole 15,000 feet?—Yes.

"Dr. Young there states, that the effect produced by the explosion of a gasometer of 15,000 cubic feet, on the surrounding building, would be equal to 10 barrels of gunpowder?—That is the case.*

"You are to be understood, that the explosion of a gasometer of 15,000 cubic feet would produce on a surrounding building, the cubical contents of which were 30,000 cubical feet, an explosion equivalent to 10 barrels of gunpowder?—It is impossible for me to say that certainly; from Dr. Young's correct mode of working, I can generally state that I believe what he has done to be perfectly correct; but, from the cursory manner in which I have looked at this calculation, I cannot speak to it; but that is my understanding of the Paper, 'Calculating upon these grounds, we find that the whole mechanical power of an explosion of 15,000 cubical feet,' instead of 14,000, 'of mixture of coal gas and common air, is equal to that of 6 cubic feet or 4 barrels of gunpowder;' and if we suppose the heated gases in both cases to escape and mix with the common air, in a building of 30,000 cubic feet, so as to produce an effect commensurate to the temperature of the whole mixture, the explosion of about 15 cubic feet, or 10 barrels of gunpowder, would be required in order to produce, like the gas, a force of about 10 atmospheres for the whole space.

"Have you yourself tried any experiments to ascertain the comparative explosive force of gas and gunpowder?—I have not.

* "By this answer I meant that it was correct that Dr. Young had so stated the effect.

"Are you of opinion that the explosive force of gas may not increase in more than a direct ratio with respect to the increase of the quantity exploded?—I certainly think it would not do so; I see no reason for supposing it should.

"Have the goodness to look at the paragraph in the *Report of the Royal Society Committee* which relates to the explosion of Mr. Lukin's seasoning-house in Woolwich dockyard, in page 4. (The witness read the paragraph.)

"Are you aware of the size of the cubical contents of the seasoning-house which is there mentioned?—Not at all.

"If you were told that the cubical contents of that building did not exceed 8000 cubic feet, would you not imagine that the effect produced by that explosion was greater than would be due to an explosion of gunpowder, in the ratio stated in the *Report of the Committee of the Royal Society*?—The fact is, all experiments on the force of explosions depend in a great measure, or entirely, on the obstruction given to the explosion. Now I do not know what the seasoning-house was; if it was a close building, and a sufficient quantity of gunpowder or gas was exploded in it, I have no doubt it would knock it all to pieces; while if that same combustible was exploded in a room where there were no glass windows, and which was open to the air; or if a barrel of gunpowder were fired in Lincoln's Inn Fields, or any large square, without confinement, it would produce no injurious effect on any of the surrounding houses; whereas, if bound round by canvass, or enclosed in an iron shell, it might produce most dreadful consequences; therefore the effect of the explosion must be comparative, and will depend upon the confinement of the combustible; and unless I were acquainted with the particular construction of the seasoning-house I cannot give an opinion.

"Taking it for granted that the dimensions were such as to give a content of 8000 cubic feet, what quantity of gunpowder would those 8000 cubic feet be equal to, according to the rule laid down in the preceding paragraph?—Between 4 and 5 barrels of gunpowder, taking the average of the two statements. I take the ten and the five as giving the average; but, at the least statement, it would perhaps then not be quite equal to two and a half.

"Do you believe that two barrels and a half of gunpowder would produce such an effect as is stated in the account of the seasoning-house at Woolwich?—If the seasoning-house was a perfectly close building, and there were no possibility for the expanded air to escape, I apprehend it might.

"It has been stated, that one of the great difficulties of exploding a gasometer was from the great quantity of atmospheric air required to mix with the carburetted hydrogen?—That is the case.

"Would not that great quantity that tends to the security of the gasometer become a source of great danger to the surrounding building; would not that which gives security in the one case produce danger in the other?—Does that mean to infer that good ventilation, or a greater quantity of atmospheric air being admitted into the gasometer-house, would increase the danger? If so, I should say not.

"Whether a small quantity of gas escaping from the gasometer would not produce a dangerous mixture in the surrounding building; and, consequently, that pro-

Mechanical
Processes.

Manufac-
tures.

perty which makes it difficult to explode a gasometer would make it easy to explode a gasometer-house?—If that gasometer-house were close that certainly would be the case.

“In very calm weather do you apprehend that a leaky gasometer might not produce an explosive mixture in the surrounding building?—That must depend entirely upon the construction of the building; for as the gas is much lighter than the surrounding air, and if we presume the leakage to take place without any very great degree of rapidity, the gas from its specific levity would ascend through the tiles or openings of the roof as quickly as it would escape from the gasometer, unless such a roof was applied as would prevent the possibility of such escape; if, for example, a slated roof, or a ceiled roof, or a vault, were placed over a gasometer, there is no doubt that an explosive mixture would accumulate there.

“Is there not so strong a chemical attraction between gas and atmospheric air that the lighter air will even descend to mix with the heavier?—That must be a slow process.”

Description of the present process of Gas making.

Abstract
from the
evidence of
Sir Wil-
liam Con-
greve.

(822.) We cannot pursue the above interesting Report to a greater length, but a few facts drawn from Sir William Congreve, one of the Members of the Committee, and official superintendent of the London Gas Works, showing the extent to which they had then (*viz.* in 1823) arrived, is too interesting to be passed over, and with this we shall conclude this historical sketch, and beg to refer those who are desirous of a more circumstantial account of the progress of the Art to Matthews's *History of Gas Lighting*, which will be found to contain a clear and candid statement of all the prominent facts of the history.

In the Report alluded to, Sir William Congreve states as follows:

Statement
of the state
of the Gas
Companies,
&c. 1823.

“At the Peter-street station, the whole number of retorts which were fixed was 300; the greatest number working at any time during the last year 221; the least 87. Fifteen gasometers, varying in dimensions, the contents computed on an average at 20,626 cubic feet each, amounting to 309,385 cubic feet altogether, but never quite filled; the working contents estimated at 18,626 cubic feet each, in the whole at 279,390 cubic feet. The extent of mains belonging to this station is about 57 miles, there being two separate mains in some of the streets; the produce of gas from 10,000 to 12,000 cubic feet from a chaldron of coals. The weekly consumption of coal is reckoned at 42 bushels for each retort, amounting to about 602 chaldrons; and, taking the average number of retorts worked at this station at about 153, would give an annual consumption of coals of upwards of 9282 chaldrons, producing 111,384,000 cubic feet of gas. The average number of lights during the year 1822 was 10,660 private, 2,248 street lamps; theatres, 3,894.

“At the Brick-lane Works, the number of retorts which were fixed was 371, the greatest number worked 217, and the least 60. The number of gasometers 12, each averaging 18,427 cubic feet, amounting in the whole to 221,131 cubic feet; and their average working contents 197,124 cubic feet. The average number of retorts worked was 133, the coals consumed 8060 chaldrons; the quantity of gas produced was 96,720,000 cubic feet, the number of lamps 1,978 public, 7,366 private, through 40 miles of mains.

“At the Curtain-road establishment, the whole number of retorts was 240; the greatest number worked in the last year, 80; the lowest, 21. The number of gasometers, 6; average contents of each, 15,077 cubic feet; the contents of the whole, 90,467; another gasometer, containing 16,655 cubic feet; the average number of retorts worked, 55; the coals consumed, 3336 chaldrons; quantity of gas produced, 40,049,000 cubic feet; the number of lamps supplied, 3860 private, and 629 public, through 25 miles of mains.

“The whole annual consumption of coals by the three different stations was 20,678 chaldrons; the quantity of gas produced, 248,000,000 cubic feet; the whole number of lamps lighted by this Company, 30,735, through 122 miles of mains.

“The City of London Gas-light Company, Dorset-street.—The number of retorts fixed, 230; the number of gasometers, 6; the largest, 39,270 cubic feet, the smallest, 5428 cubic feet; two large additional gasometers nearly completed, contents of each, 27,030 cubic feet, making in the whole 181,282 cubic feet. The number of lamps lighted, 5423 private, and 2413 public, through 50 miles of mains. The greatest number of retorts worked at a time, (in 1811,) 210, the least, 130, average 170. The quantity of coals carbonized amounted to 8840 chaldrons; produced 106,080,000 cubic feet of gas.

“The South London Gas-light and Coke Company, at Bankside.—The number of retorts was 140; gasometers, 3; the contents of the whole, 41,110 cubic feet; and their mains from 30 to 40 miles in length. At their other station in Wellington-street, they had no retorts in action; but three large gasometers were erected, containing together 73,565 cubic feet, which were supplied from Bankside till the retorts were ready to work.

“The Imperial Gas-light and Coke Company were erecting, at their Hackney station, two gasometers of 10,000 cubic feet each, and about to erect four more of the same size. At their Pancras station they had marked out ground for six gasometers of 10,000 cubic feet each.”

The Report states, “that in the year 1814 there was only one gasometer in Peter-street, of 14,000 cubic feet, belonging to the Chartered Gas-light Company, then the only Company established in London. At present there are four great Companies, having altogether forty-seven gasometers at work, capable of containing in the whole 917,940 cubic feet of gas, supplied by 1315 retorts, and these consuming 33,000 chaldrons of coals in the year, and producing 41,000 chaldrons of coke. The whole quantity of gas generated annually being upwards of 397,000,000 cubic feet, by which 61,203 private and 7268 public or street lamps are lighted in the Metropolis. In addition to these great Companies, there are several private Companies whose operations are not included in the foregoing statements.”

Properties of different kinds of coal.

(823.) *Description of the process of gas making.*—It will have sufficiently appeared, from the preceding historical sketch, that great changes have taken place in the arrangement of gas Works, in the forms of the apparatus, and in fact in the general principle of the operation; but it will be unnecessary for us to enter here into an account of all these changes; it will be sufficient to explain to the reader the nature of the improved practice as it is now with little variation carried on in all our principal Works.

Mechanica.
Processes.

Processes
in the
making of
gas.

Manufac-
tures.

It will of course be conceived that, in so large establishments as the London Gas Works, different buildings must be provided for the different processes; viz. one for the retorts, called therefore the retort house, another for the condensing, another for the the purifying, &c. The gasometers are placed in the open air, and the whole must of course cover a considerable space, particularly as these separate buildings are frequently at some distance from each other. The reader must not therefore consider the plate we have given as exhibiting any actual establishment, but simply as a drawing intended to bring into one point of view the entire operation from the retort to the gasometers. In plate liii. fig. 1, we have endeavoured to give a connected view of the whole process, by referring to which the following explanation will be easily understood. A represents the fire-place or furnace by which the retorts containing the coal for distillation are heated, and *a, a, a*, show the retorts as they are arranged and set in the frame or oven of brick-work; our drawing represents five, but there may be more or less than this number. The mouth-pieces carrying the conducting pipes are screwed on air-tight, the top of these pipes are connected at top with a bridge-piece, and they then recurve and descend into the hydraulic main. The latter pipes are called dip pipes; they fall immediately behind the conducting pipes, so that their descent into the hydraulic main B cannot be traced.

The hydraulic main B is an iron pipe ranging the whole length of the furnace, and about 12 or 14 inches diameter; this is first about half filled with cold water, into which the dip pipes are inserted; but this water, soon after the process commences, is replaced by the tar and ammoniacal water deposited from the gas, and which as it rises above the level is carried off by the pipe to the tar vessel. The gas, descending first through the pipe *z*, is carried to the condensing vessel C, when it is made to pass through a succession of pipes, as will be more fully explained, in the course of which it deposits a further quantity, indeed nearly all its tar and other condensable impurities, which are first deposited in the lower vessel *i*, from which they flow as they rise into the tar cistern D, whence they may be afterwards drawn by cocks.

The gas now passes through the pipe *w* to the purifier, which is a close iron vessel containing lime water: it is divided by horizontal partitions into three chambers; within it are central cylinders open at bottom, but closed at top. The gas enters the lower one from the pipe *w*, into the central cylinder *p*, from which it escapes under the flanch *i*, and, passing through the pipe *v*, enters the second interior cylinder *q*, whence escaping again under the flanch *r*, it passes through the pipe *t* into the upper cylinder *s*, and thence through the pipe *u* to the gasometer F, where it is preserved for general use.

This description will be sufficient for the present. We shall now examine the apparatus and illustrate their use and intention more minutely, and shall also as we proceed point out some differences in them as they have been suggested by different gas engineers.

Nature and
product of
the coal.

(824.) *Properties of different kinds of coal.*—The raw material of coal gas is bituminous coal, of which there are two kinds; namely, that which when in small pieces, and thrown on an open fire, concretes into a mass by a sort of semifusion, forming cinder, and that which has not this coking property, but burns away to a white ash without yielding any cinder. If the only object of consideration in the selection of coal were the goodness of

the gas, *i. e.* the whiteness of the light which it affords on combustion, the non-coking coals would deserve the preference, especially those kinds that have a slaty structure, a grey rather than a full black colour, which do not soil the hands, and crackle when first thrown into the fire; such is the celebrated cannel coal of Lancashire, from the neighbourhood of Wigan and of Manchester, the splent coal from the collieries near Edinburgh, and an inferior kind of cannel coal from near Sheffield. But, as in all gas Works, especially those of London, and other places where coals are dear, the sale of the coke is looked to for reimbursing a considerable proportion of the cost of the coals, such must be selected as will yield a coke at the same time bulky and of good quality, the latter that it may fill well in the measure, coke being estimated by measure and not by weight. On this account the cannel coal of Sheffield, though it yields a large quantity of very good gas, yet because it does not coke in the retort, and comes out in smaller pieces than it went in, affords a perfectly unsaleable coke, and therefore is less profitable than the coking coals of Durham and Northumberland, though the gas from these latter is inferior both in quantity and quality. The market price of the coal is also a circumstance to be taken into consideration, for as the ultimate object of gas making, as well as of every other manufacture, is profit to those concerned in it, the seller will of course either raise the price or deteriorate the quality of the article which he deals in, as far as he can safely do so without hazarding the loss of his present customers, or diminishing his chance of gaining new ones. Whatever be the kind of coals selected for use, it is absolutely necessary that they should be quite dry, otherwise the retort will be cooled down by the conversion of part of the water into steam, while the other part by its decomposition will produce gases very injurious to the real coal gas.

(825.) *Of the retorts.*—The vessel in which the coal is decomposed, and the gas generated, is called, without much propriety, a retort; it consists of a cylinder, generally of cast, sometimes of hammered iron, of 6, 7, or 8 feet in length, and about 12 inches in diameter, and closed at one end. Five retorts are usually contained in one oven, being arranged in two rows; three in the lower one, and two in the upper: but sometimes more, and sometimes less are used; the flues of the oven being so contrived as to distribute the heat as equally as possible. In our drawing, these retorts, fixed in their places, are denoted by *a, a, a*, see plate liii. fig. 1. The advantages of the cylindrical form given to the retort are, that it is the least expensive, and that if it begins to wear away too rapidly in any one part, in consequence of its being exposed to a greater intensity of heat, the retort may be partly turned round, and the weak place thus removed from further injury. The disadvantage of the cylindrical form is that, when the charge of coal is put in, it is in the form of a segment of a cylinder, and consequently diminishing in thickness continually from the middle towards the sides. Now it is of advantage that the coal in every part of the retort should be acted upon as equally as possible by the heat, and with this view in many Works the cylindrical retorts have been replaced by those of an elliptical figure, the longest diameter being horizontal, or by four-sided ones, either plain, or with the edges flattened so as to make them octagonal, or finally oven-shaped, that is, flat at the bottom and concaved above. To each retort is attached a mouth-piece, also of iron, having a round hole at top to receive the end of

Mechanical
Processes.

Description
of the
retorts.

Manufac-
tures.

the conducting pipe, and capable of being closed in front by a plate of iron and a pressing screw. The proper working temperature is a cherry-red; when therefore the inside of the retort shows this colour, it is charged either by shovels, or by filling an iron scoop like a marrow-spoon with coals, thrusting it into the retort, and then turning it round; by this means the coals are of course discharged and the scoop is withdrawn, leaving the retort about half filled; the plate is then fixed to the mouth-piece without loss of time, and the gas is prevented from oozing out round the edge, by the application of lime-lute. The duration of a retort is very various, depending on a number of circumstances, but, accidents excepted, it hardly ever gives way in less than six months, and is often found to last more than double that time. The destruction of the retort goes on, at the same time, both from the outside and the inside; from the outside by the usual action of violent heat and air, from the inside by the reaction of the coal itself; in consequence of which the iron enlarges in bulk, and assumes the appearance of finely laminated black chalk, becoming at the same time quite soft and crumbly.

Each charge of coal continues in the retort six or eight hours, the latter being the most usual time. Even then the whole of the gas has not been driven out; but the rate of its production is so far diminished, and its quality is now become so far inferior to the average standard, that it is not worth while to carry on the process any farther. The plate which closes the mouth of the retort is therefore removed, and a volume of livid yellow flame pours out; the coke is withdrawn by means of long bars bent at their ends to a right angle, and as it falls from the mouth of the retort is extinguished by a pail or two of water thrown on it. The retort is now ready for a fresh charge.

Quantity
of coke ob-
tained.

The proportion of coke obtained from a given weight of coal varies considerably, according to the nature of the coal and the heat to which it has been exposed; and the quality of the coke is also affected by the same circumstances; a hot fire producing hard coke, a more moderate one a soft coke. From 22.5 to 34.5 per cent. will probably include the greatest and least loss of weight that coal undergoes by the process of distillation. If the coke is of good saleable quality, it usually, notwithstanding this diminution of weight, increases in bulk about one-half; 14 bushels of coal affording from 20 to 21 bushels of coke. The fuel used in heating the retorts is coke, and in some Works part of the tar is applied to the same use. The proportion of coke thus consumed is from 30 to 35 per cent. of the whole quantity produced. Let us now follow the course of the gas from the retort to the condensing main.

Progress of
the gas
from the
retort to
the con-
denser.

(826.) *Hydraulic main.*—On leaving the retort, the gas first enters an upright pipe called the conducting pipe, and deposits in it a quantity of hard pitchy matter, which would soon stop it up, if a bar were not thrust up it, in order to clear it whenever a new charge of coals is put into the retort. From the conducting pipe, it passes into a bent one called the bridge-piece, and then descends through the dip tube, which discharges it into the hydraulic main. In our drawing the dip tubes and bridge-pieces are hidden by the upright pipes above referred to.

After the retorts have been supplied with coals and heated as above described, the next object is to separate the different volatile substances which are in the first instance combined with the gas, some of which are separated by condensation, and others by a different process

which will be explained. To effect the condensation, Mechanical recourse is first had to the hydraulic main B. This is a Processes. strong cast-iron pipe of 12, 14, or more inches in diameter, and of the whole length of the several furnaces in which the retorts are worked. Its position requires perfect horizontality, and it is generally placed over and in front of the brick-work of the furnaces, and is supported by appropriate iron pillars. It has already been stated, that a pipe ascending from each mouth-piece of the retorts, of about 3 inches' diameter, and 4 or 5 feet long, is made afterwards, by recurving or by a bridge-piece, to descend again into the hydraulic main, where each pours its content of foul gas. As the principal purpose of this main is the condensation of the substances which the heat first expels from the coal, it is constructed so as to contain a quantity of cold water. One end of it is perfectly closed by a flanch, and the other has also a similar flanch, but a little above its horizontal diameter there is a pipe through which the water from the main first passes, and afterwards, as it is formed, the tar and ammoniacal water into a proper receptacle below; by this means the tar covered with a thin coating of the fluid is kept at a proper level in the main, the dip pipes being always immersed a few inches below the general surface. One great advantage attending this apparatus is, that by this means the pipe of each retort is insulated from all the others, so that when any one is opened it can only emit its own contents of gas, whereas if they were all in connection, there would be such a flow as would prevent the filling it again with coal. By the other pipe *z* the gas is conducted into the condenser.

(827.) *Condensing main.*—From the hydraulic main, Description of the con- the gas passes by the pipe *z* into the condensing main denser C, where it is cooled, and parts with nearly the whole of the tar and ammonia, and some other condensible impurities. The more perfectly the tar is separated, the more easy and complete is the subsequent purification, and therefore it is detained in the condenser as long as the necessary routine of business will allow. The usual form of the condenser is a rectangular vessel divided by two sets of partitions at right angles to each other, with two or three rows of cells, each row containing six or eight cells; the partitions do not descend quite to the bottom of the vessel, so that the fluids deposited in the different cells may be discharged into the tar cistern by a single pipe. The cover of each cell is pierced with two holes for the reception of an upright pipe bent double, one leg of each pipe being inserted in the cover of one cell, and the other leg in the cover of the adjacent cell; by which arrangement the gas passes through all the pipes and into every cell, and in this long transit cools down to the temperature of the air, and deposits nearly the whole of its tar and ammoniacal liquor, which are discharged into one covered pit, called the tar cistern, shown at D, the ammoniacal liquor occupying the upper part. Two cocks, or two pumps, a long and a short one, are fixed in the cistern, the former of which brings up the tar, and the latter the ammonia.

A still more simple form of condenser, proposed by Mr. Lowe, is merely a pipe with a number of ascending and descending bends in it, fig. 4. From the bottom of each bend descends a small pipe *a* bent up at the end, through which the tar and ammoniacal liquor are discharged; this affords an opportunity of procuring tar of two or three qualities, which may thus be applied to the uses most appropriate to each

Manufactures.
Produce of
tar and
ammonia.

A chaldron of coals of average quality will give about $1\frac{1}{2}$ or $1\frac{1}{2}$ cwt. of tar, and from 15 to 18 ale gallons of ammoniacal liquor, and as the demand for these articles is very uncertain, they often accumulate to an inconvenient extent. Under these circumstances, part of the tar is usually employed as fuel in the retort house, and in some of the gas Works the ammoniacal liquor is manufactured into sal ammoniac, and other saleable forms of this alkali.

Process of
purifying.

(828.) *Description of the purifier.*—From the condenser the gas passes to the purifier E, where the sulphuretted hydrogen, and carbonic acid, and some other gases, none of which are condensable by mere cooling, are separated. The substance, by the chemical action of which the gas is purified, is lime usually mixed up with water to the consistence of thick cream. But, as a gas is not very readily cleared of any impurity by washing in a liquid, it is made to pass in succession through at least three purifying vessels, sometimes enclosed in one. These are covered air-tight cisterns of a cylindrical form, with an upright shaft in the axis, to which are attached arms or paddles for the purpose of agitating and stirring up the liquor, and thus preventing the lime from sinking to the bottom. The gas enters at the lower part of the purifier, and is first received under the flanch or umbrella-shaped plates, as already described, from the margin of which it is continually escaping in bubbles; these bubbles are again intercepted by a second plate, and thus fresh surfaces of the gas are continually exposed to the action of the lime liquor. From the first cistern the gas passes to the second, and from the second to the third. Here its purity, that is, its freedom from sulphuretted hydrogen, is tested, by letting out a little of it through a stop cock, and exposing to the jet a white paper moistened with a solution of sugar of lead. If the smallest portion of sulphuretted hydrogen remain in the gas, the paper will be tinged more or less brown; and, when this happens, the contents of the first purifier, that is, of the purifier into which the impure gas first enters, are discharged; and it is filled with fresh lime liquor and then receives the gas, after having passed through the two former purifiers; but as this cannot be done without a somewhat complicated arrangement of pipes and stop cocks, a simpler plan is adopted in some Works, by letting the contents of the second purifier into the first after the spent liquor has been discharged from that, and then letting the liquor of the third purifier into the second, and filling the third purifier with entirely fresh lime liquor.

The odour of the spent liquor is intolerably fetid, being a compound of that of sulphuretted hydrogen, tar, and ammonia. On the first establishment of gas Works in London, it used to be discharged into the drains, to the great annoyance of the whole neighbourhood; at present it is put into open vessels placed below the grate of the furnaces; here the watery part exhales, and, in so doing, greatly protects the furnace bars from the action of the intense heat in their vicinity; the residue of the lime liquor, now of the consistence of mortar, is partly used as lute for the mouths of the retorts, and what is not wanted may be carted away without inconvenience.

Another form of purifier, for which Mr. Phillips of Exeter obtained a patent, is to mix the lime only with such a quantity of water as shall bring it nearly but not quite to the consistence of mortar, or rather perhaps to that of moist sugar. This is to be spread on perforated plates, which are to be so arranged in boxes that the gas shall pass through the perforation, and thus be

VOL. VII.

brought in close contact with the lime. Two advantages are considered to attach to this plan, namely, that the necessity of subsequently evaporating the waste liquor is avoided, and the gas is presumed to be better, as retaining the whole of its olefiant gas, to which the whiteness of the flame is supposed to be owing, whereas the same gas being slightly soluble in water, it is to be presumed that more or less of it must be lost in the mode of purifying by milk of lime.

In this case the gas passes into and out of the purifier by a four-way cock, so that it may be sent either from the upper chamber downwards, or from the lower chamber upwards, a change which is necessary, because that platform of lime first acted upon by the gas will lose its power soonest; when this happens, the direction of the gas is reversed.

(829.) *Transmission of the gas to the gasometer.*—From the purifiers, the gas in many Works passes immediately into the gasometers, but in others it passes into a large revolving meter, described below, where it is measured by reading off the index, and the temperature is taken. These observations being made and registered at short intervals enable the superintendent of the Works to ascertain whether the retort men have been duly attentive to their business, and he is thus also informed of the total quantity of gas produced in 24 hours. This latter result may be more accurately obtained from the use of such a revolving meter than by a gage attached to the gasometer, affording, as it does, a more accurate correction for temperature. We shall describe this more particularly in a following page; it is merely alluded to here, as the apparatus is not shown in the drawing.

From the principal meter, when there is one, or from the purifier, when there is not one, the gas passes into the gasometer, or, more properly speaking, into the gas-holder. This is a hollow cylinder of sheet iron containing from 20,000 to 30,000 cubic feet. It is floated in a tank of water and is counterpoised by weights, the due proportioning of which adjusts the pressure on the enclosed gas, which pressure will generally be found to vary according to circumstances from half an inch to 3 inches of water.

Having thus traced the gas from the retort into the gasometer, this is the proper place to state the average quantity of gas produced from a given quantity of coals. This is usually estimated at 10,000 cubic feet for a London chaldron, but liable to variation according to the kind of coal operated on, and the length of time employed in distilling each charge. Some of the London Companies get, we believe, from certain Durham and Northumberland coals from 11,000 to 12,000 cubic feet, while cannel coal, even of an inferior sort, will yield as much as 14,000 cubic feet. Mr. Lowe's reciprocating retorts, in which the gas from each fresh charge passes over the red hot surface of the preceding charge, are said to yield from common coals far more than the highest of the above-mentioned numbers, in consequence of the decomposition of a large proportion of the tar, by the conversion of it into gas.

Instruments for measuring the quantities and qualities of the gas, for regulating the supply, &c.

(830.) In the preceding section we have endeavoured to give a general and connected description of the process of gas-making without interrupting it by any collateral details. It may, however, be proper to repeat again that the pipes through which the gas passes from the retorts to the

Mechanical
Processes.

Transfer of
the gas to
the gaso-
meter.

Quantity
of gas from
a given
quantity of
coal.

Description
of different
apparatuses.

Manufac-
tures.

condenser, purifier, and gasometer, which, in our drawing, are all placed contiguously, may be at considerable distances from each other, and that, in the course of this tract, gauges are placed in different situations, so that, by turning a cock, the pressure of the gas in any of the pipes and vessels may be ascertained, any stoppages detected, and of course accidents prevented.

Another precaution against accident, and for announcing a stoppage in the pipes leading from the hydraulic main, is the application of a small gasometer at the other end of the main from that in which the gas and tar pipes are inserted; a small pipe from this end entering under the gasometer, in case of any stoppage in the pipes, raises the gasometer to a height proportional to the pressure, and when at a certain elevation it lifts a catch; this lets go a weight, which running down thereby rings a bell, announcing to the men on duty that a stoppage has taken place.

The next intermediate application is that of a stopcock, in immediate connection with the last chamber of the purifier; this being turned at any time, and the gas lighted and applied to the test-paper already noticed, will point out the state of the gas in this important stage of the operation.

Gas meter.

(831.) *Gas meter.*—In our Plate, the gas is represented as passing immediately from the purifier to the large gasometer by a short pipe or tube; but the gasometers are always at a distance from the purifiers, and generally the gas in its passage is made to pass through a large gasometer, by which may be ascertained the exact quantity of gas made in a given time. Some of these are sufficiently large to measure to the amount of thirty or forty thousand cubic feet per hour, and some of them have also an appendage by which they are made to register the number of feet made per hour, both day and night. In this form they are called tell-tales, but without this appendage they differ only in size from the smaller sort employed in private houses and establishments for ascertaining the quantity of gas consumed when the parties prefer paying at per cubic foot, instead of per burner. The same description will therefore serve for both; it is, however, although very simple in its operation, rather complicated in its construction, and the following description is intended rather as explanatory of the principle of the instrument than of the instrument itself, which indeed has been considerably changed in form since it was first projected by Mr. Clegg.

In plate liii., fig. 2 and 3, we have given two sections of this instrument at right angles to each other; *c c c* is a close hollow drum, one face being removed to show the four partitions in it; at the centre there is a hole pierced through both sides or ends of the drum; *d d d d* is an interior drum having partitions in it, shown in fig. 3. This interior drum turns on an axle *i*, the axle passing through the bar *m m*; *a* is the pipe by which the gas enters into the Machine, and *h* that at which it escapes after its measure is ascertained, in the way described below; the four compartments *t t t t*, into which the interior drum is divided, communicate, by holes or slits *b b b*, fig. 3, with the hollow in the centre, where the gas is first let in; they have no direct communication with each other, but are connected with the outer space by the holes *e e e e*. This inner cylinder turns freely on the axle running through *i*, being fixed at one end to the cylinder, and at the other kept steady by the cross bar. This end of the pivot does not reach to the outside of the cylinder, but is inserted in a

hole drilled in the side of the pipe *a*, which enters the internal cylinder. The other end projects from the inner cylinder, and reaches through the hole in the outer cylinder to a tin cup, *n n*, in a hole of which it turns. Within this cup a cog-wheel is fitted to the pivot, but not shown in the figure, by which its revolutions are recorded on the face of a dial by the aid of clock-work. Water is poured in at a small pipe in the outer cylinder at *n*; there is also another pipe or opening at *k*, whereby the water escapes when it has attained its proper level, which is thus insured; both openings are then closed by screw stoppers, and the Machine is now ready for use. The operation of this ingenious instrument will be easily comprehended if the foregoing description has been well understood. The gas to be measured is admitted through the pipe *a*, which is bent upwards, so that its orifice is above the level of the water. The small portion of the central hollow above the water is soon filled, the gas then flows through *b* into that division which is almost all under water; this in the figure is on the left hand, marked *t*. The pressure of the gas on the surface of the water forces that division to rise, and, consequently, the whole internal cylinder to turn round. When this division is quite full of gas, the hole *b* will be just dipping under the water, and water will flow into it instead of gas. At the same moment, the slit *e*, by which the division communicates with the outer cylinder, will rise above the water, and the gas will flow out as the water enters the hole *b*. The next division will then be filled in the same manner, the inner cylinder, with its pivot and the cog-wheel attached, will continue turning round, and the gas which has passed through it will leave the Machine through the pipe *h*. It is now clear that in one turn of the inner cylinder as much gas will pass through the meter as is sufficient to fill up its four compartments; and if that quantity be known, it will be easy to arrange a piece of clock-work, attached to the Machine, so as to point out on a dial the actual number of cubic feet that has passed through it.

(832.) *Of the supply of gas.*—The gas is discharged from the gasometer into the distributing mains by the pressure exerted on it by the weight of the gasometer itself, adjusted by the counterpoise; but the variations of pressure in the main itself depend on the due regulation of the valves which command the communication between the gasometer and the main; in this case, therefore, a high pressure indicates a copious supply, and a low pressure a smaller supply. During the day, no greater supply of gas is wanted than is necessary to be an equivalent to the loss from leakage, otherwise atmospheric air would find its way into the pipes, and might occasion explosions. But as evening draws on, the lamps, both public and private, are lighted, and therefore a full supply of gas is required. After nine o'clock, some shops are shut up, and therefore the consumption of gas is diminished; at a later hour more lamps are put out, and at dawn the public lamps also are extinguished. Now that there may be no deficient or redundant supply, during this time, great care on the part of the person entrusted with the valves is required, and the accuracy with which he performs his duty is shown by the Pressure Indicator, which was invented by Mr. Crosley. It consists of a small gasometer, the interior of which communicates with the gas main by a small tube. An air vessel within this gasometer makes it float when down at its lowest immersion, so that in this situation its interior is in equilibrium with the atmospheric pressure, and

Mechanical
Processes.Pressure
Indicator.

Manufac-
tures.

by increasing the pressure on the gas in the main, the pressure on the air in the gasometer is equally increased, and thus the gasometer floats higher. This variation of height is estimated by a scale divided into inches and tenths. The guide rod of the gasometer has a spring pencil-holder attached to it, adapted to press the point of the pencil against a piece of paper divided vertically into heights, and horizontally into intervals of an hour each. The cylinder moves on its axis at a given rate, being connected with a time-keeper, and thus the variations of pressure, as indicated by the pencil attached to the gasometer, are also connected with time by means of the revolving cylinder.

Gas go-
vernors.

(833.) The *gas governor* is an instrument, invented by Mr. Clegg, for regulating, like the last, the inequalities arising from the irregular pressure of the gas-holders, as well as from the putting out of the lights at different periods of the night. This contrivance consists of a small gasometer of sufficient weight for producing the required pressure; the interior of it is in direct communication with the pipe through which the gas passes. This gasometer is connected with a regulating valve, so that when the pressure, at any time, increases, the gasometer rises and contracts the opening; and, on the contrary, if the pressure diminishes, the gasometer falls and increases the opening. In every case, the aperture is always in unison with the demand, preserving the flame at one uniform height. Its purposes are more effectually accomplished by placing one, on a small scale, in each house; but one on a larger scale, placed at the main outlet at the gas Works, will equalize the general pressure, and seems to be absolutely necessary where governors are not individually used. This is a self-acting Machine, and requires no alteration when once adjusted. The following description will probably render it intelligible:

Pl. liii.
Fig. 5.

Fig. 5 is a section of the governor, and A B C D exhibit the outer case; this is made of sheet iron or copper, with the top and bottom closed, and both the inside and outside are also japanned; *a b c d* show the form of the small gasometer, *e f* the pipe through which the gas enters, and *g* the pipe by which it passes out. The conical valve attached to the bottom of the upright spindle rises or falls so as to contract or enlarge the aperture E, as the gasometer ascends or descends by the entrance or passing out of the gas, and F G is a short hollow cylinder or cup in which the outer case is fixed at the centre of its base. Mr. Crosley has made some improvements in the construction of the governor for regulating the supply at the main outlet of the Works, so that by its own action the pressure is increased or diminished with the quantity supplied. One of the modes he employs is in the construction of the small gasometers. Some years back, by making an experimental gasometer on a small scale, and requiring uniform pressure for comparing the intensities of light, instead of using, as heretofore, a compensating chain, which it was not easy to make free from friction, he found that he could effect the same in a more simple way by making the gasometer less in diameter at the top than at the bottom. Hence, by increasing this difference, the gasometer may be made to vary its pressure to any required degree. He also effects the same purpose by employing a gasometer of the common construction, making the necessary compensation by means of a cycloidal wheel, over which the balance-weight is suspended. This wheel is formed with moveable pegs

for varying the curve, and adapting it at pleasure to any required variations.

By certain modifications of the governor, Mr. Crosley has rendered it capable of regulating the discharge of gas from a portable gas vessel, so that, without any adjustment of the valve, the flame is preserved uniform from the beginning, through all the variations of pressure, from thirty atmospheres down to that of common gasometers.

(834.) *Apparatus for registering the impurities of gas.*—This is also a simple but very ingenious instrument of Mr. Crosley's invention, intended for indicating and registering the impurities of the gas, and which, at the same time, denotes the periods when they occur.

The arrangement of this apparatus consists of a circular card placed upon an axis, which communicates with a time-piece. Upon this card three circles are described, which are divided into 24 divisions by lines drawn from the centre, corresponding with the hours of day and night. The two largest circles, which are of equal breadth, occupy the marginal space at the outer extremity of the card; these are coated with the usual solutions or tests for sulphuretted hydrogen and ammonia, and a very small jet of gas, from an orifice adapted to each of the circles, is made to play constantly over them. The inner circle being divided into spaces that are marked from 1 to 12 for *day*, and 1 to 12 for *night*, hence, as the axis of the time-piece performs its revolution with the card attached to it, the *impurities*, and the *time* when they happen, become exactly registered: and by changing these cards daily a perpetual register is obtained. The principle on which it acts renders the managing of it readily attainable; and its utility is so obvious, that perhaps it will eventually come into general use.

(835.) *Instrument for ascertaining the specific gravity of the gas.*—This is an exceedingly simple instrument. It in some measure resembles in form a small flask, with an opening and cap at each end, which may be completely discharged of the air, and filled with gas, by placing one of its ends upon a pipe or cock, of the same size, and passing a current of gas through it in the following manner. A projection is placed on each side of the flask, by which it is intended to be held in the hand, so that the temperature of the gas or air within may not be increased.

Previously to the flask being filled with the gas intended to be weighed, let it be freed from foul air or gas, by taking off the caps from each end, and passing a current of fresh air through it, until the air within is the same as without; this may be easily effected by moving it quickly and repeatedly to and fro, endways, in the air; the caps may then be put on, and the flask accurately balanced; this being done, take off the caps, and pass a current of gas through it during about ten seconds of time; then put on the cap at the upper end, and, at the instant of disengaging the bottom end of the flask from the pipe or cock, put on its cap, and immediately weigh it again, when the diminution or counterweight, required for restoring the balance, will be a datum for determining the specific gravity of the gas.

Namely, as the weight of the air is to the weight of the gas, so is the specific gravity of the air, which is taken at 1000, to the specific gravity of the gas. In order to facilitate the computations there is sold, with the instrument, a table containing the weight of 50 inches of air in grains for all the usual barometric pres-

Mechanical
Processes.

Apparatus
for ascer-
taining the
state of im-
purity.

For deter-
mining the
specific gra-
vity.

Manufac-
tures.

tures and temperatures. The rule therefore is, from the weight shown in the table for any given pressure and temperature, subtract the counterweight above referred to; the remainder is the weight of the gas. Divide this remainder by the tabular weight, and the first three figures will be the specific gravity of the gas, that of the air being 1000.

Oil Gas.

Process of
making oil
gas.

(836.) We have in the above notice confined our account of gas-lighting to that of coal gas only; but our Treatise would be incomplete if we did not slightly allude to the attempt made for substituting oil gas for coal gas, but as it may be said to have been, if not a failure, yet certainly not attended with all the advantages the projectors anticipated, a very little illustration of the principle of operations will be sufficient. The light from oil gas is generally admitted to be more pure than that from coal gas, particularly as the latter was manufactured in the year 1815, the period at which the patent for oil gas was obtained; and its purity and freedom from the bad smell which attended the former gave it a preference for private houses. In point of economy, however, it had no chance with coal gas, and it is at this time, we believe, scarcely any where employed. The process of making it, as recommended by Messrs. Taylor and Martineaux, will be understood from plate liii., fig. 6.

Pl. liii
Fig. 6.

Here A represents a section of the furnace or oven for heating the retort to a red heat. The front of the retort, which is a cylindrical cast-iron vessel, is shown at B, the mouth is fitted with a cover to completely close it as in the coal gas retort, and it is partly filled with coke and broken bricks, so that the oil which falls by drops upon the heated substance may be exposed to as large a heated surface as possible, in order the more completely to decompose it and convert it into gas.

C is a section of a copper vessel to contain the oil, which, by means of a cock *a*, is allowed to drop regularly through the pipe *b b*, upon the heated matter in the retort, where it is decomposed and converted into gas and other volatile products, and these pass along the pipe *c* into the square cistern or condenser D. This condenser consists of two iron vessels, one within the other, and the space between them is filled with cold water, in order to keep the inner one cold, and thereby to condense the products of the distillation as they pass through it. The oil which the heat may convert into vapour without decomposition, condensing again into oil, forces through the pipe *d*, and again enters the oil vessel C, to be with the other contents again submitted to the retort.

But the gas ascends through the pipe *d* to the purifier E, which is filled with oil nearly to the top, and a board is placed obliquely across it, that the gas, by entering at the lower end, may have to pass over a large surface of the oil, and become thoroughly washed before its transit through the pipe *f* to the gasometer. The upright pipe *g* preserves the oil at an equal height in the purifier, and the funnel *h* is for supplying the oil vessel. The use of the cock *i* is for drawing off any water that may mix accidentally with the oil.

F F represents the cast-iron stand which supports the condenser, purifier, and oil vessels. The gasometer is not shown. It, of course, is similar to that above described for coal gas.

Portable
gas.

Portable Gas Vessels. The gas obtained, according to the principles last described, from oil, possesses, as we

have stated, a greater degree of purity than coal gas, and, consequently, affords a greater degree of light according to its bulk, and, therefore, a less quantity of it and smaller burners are required for a given amount of illumination. This property led to the idea of moveable or portable gas vessels, which, in some cases, have been found very convenient. Portable gas consists of oil gas greatly compressed and forced into strong wrought-iron vessels, which are made of various dimensions according to their intended purpose, and of various forms, many of them highly ornamental.

Mechanical
Processes.

For common purposes, where ornament was not studied, they were commonly cylindrical with hemispherical ends, with an opening fitted with a valve at each end, one for admitting the gas, and the other to supply the gas for consumption.

A Company was established in London, called the Portable Gas-light Company, having for their engineer M. D. Gordon, the inventor of this species of gas-light, who supplied private families with their gas at a certain price per foot, sending round at certain periods for the vessel, and returning it filled with gas compressed about thirty times.

This high pressure it is evident required vessels of great strength, and perhaps, after all, it required some practice before a person or a family could sit down without apprehension to a light proceeding from a vessel on the table before them, so highly charged that any fall, flaw, or accident, would expose them to the most serious disaster. Great precautions were, therefore, taken by the proprietors to have their vessels submitted to a severe proof before they were filled with gas for use, and we are not aware of any accident from explosion having occurred. The price at which the gas is served to the Public is 6s. 3d. for 100 cubic feet.

We have been greatly indebted in the writing the preceding sections to various Papers in different Philosophical publications, to the *Phil. Trans.*, to an ingenious and useful Work by Mr. Packston, and particularly to two Works by Mr. Mathews, one on the History and another on the Practice of the Art. We are also much indebted to Arthur Aikin, Esq., Secretary to the Society of Arts, for the use of a MS. he had compiled for a Lecture at that valuable Institution.

Lighthouses.

(837.) Amongst the Works of public utility which are intended to be treated in this Division, there are few of greater importance to a maritime power like Great Britain than Lighthouses, whether they be considered with reference to the immense value of the merchandise which is thereby protected from destruction, or to the many lives which, without such guides, must inevitably be annually sacrificed on a sea-girt coast like that of England. These circumstances, and the very large revenue and expenditure of the Lighthouses on our shores, have on different occasions attracted the attention of Parliament. During the last year (1834) a long and laborious investigation of the subject took place before a Committee of the House of Commons, and a Report, with the Minutes of the evidence, has been recently printed by order of the House in a large volume, from which we intend to abstract briefly all the more important and interesting particulars. The construction of Lighthouses has already been given in our alphabetical arrangement, so that in the present notice it will only

Manufac-
tures.

be necessary to treat of what may be called the statistics of the subject, and to give an account of the experiments which have been made with a view to improvements in the system of lighting, which, although very considerable within the course of a few years, it is very desirable to extend still further, by availing ourselves of all the advantages furnished by the various and valuable discoveries in Chemical, Optical, and Mechanical Science. It will be well, however, before we enter upon a description of these experiments to show the great extent of the present system, the nature of the lights, the consumption of oil, &c., the revenue derived from light and beacon dues, and the application of the funds thus arising.

By whom,
and by
what
authority,
erected.

The erection of public Lighthouses in England has been undertaken either by individuals, or by the Brethren of the Trinity House, to whom patents for the purpose have been granted by the Crown, on the presumed general wish of those interested that the same was necessary, and would be useful; and petitions from merchants and shipowners have generally been presented at the same time to the Crown, offering payment of certain tolls or dues for the maintenance of such lights when erected.

The public general lights of Scotland are under the management of a Board, denominated the "Commissioners for Northern Lighthouses," incorporated as such by the 38 Geo. III. c. 58; and the Commissioners hold their office at the Board by virtue of the public situations they fill. They are twenty-five in number, and, with the exception of the Lord Advocate and the Solicitor-General for Scotland, are all municipal offi-

cers. Their services are gratuitous. They have no power to interfere with any of the local or harbour lights.

The lights of Ireland are under the superintendence of the Ballast Board, a Corporation consisting of twenty-three Members, who are the Lord Mayor and Sheriffs of Dublin, three Aldermen, chosen by the Board of Aldermen, and seventeen other individuals, appointed in the first instance by the act of incorporation, but who have the power of filling up the vacancies.

The public general lights of England are seventy-one in number, including one on the Island of Heligoland, off the coast of Holstein. Fifty-five of these general public lights belong to the Corporation of the Trinity House, Deptford Strond, the revenue from them being managed for the benefit and objects of that Institution. Three have been leased by the Trinity House to individuals, seven have been so leased by the Crown, four are held under patents subsequently sanctioned by Acts of Parliament, and two are under the management of the Trinity House, but the deficiency of the dues at one (Heligoland) is made up by Government, and the other is supported by the Admiralty.

The following is a statement of the lights belonging to or under the management of the Trinity House of Deptford Strond, distinguishing whether fixed, revolving, or floating; showing the number of burners in each, the annual consumption of oil, the number of keepers, with their salaries and allowances; the tonnage of the light vessels, the number of the crew of each, their wages and allowances; together with the salaries allowed to the agents of the respective establishments. February, 1834.

Mechanical
Processes.

Statements
of the several
English
Light-
houses.

(838.) Lighthouses belonging to the Corporation of the Trinity.

Name of Light and Description.	Number of Burners.	Annual Consumption of Oil.	Number of Keepers, and Salaries and Allowances.	Salaries to Agents.
		Gallons.	£. s. d.	£. s. d.
Fern, Inner, revolving	7	{ 284, including } { Leading Light. }	One 65 0 0	75 0 0
Fern, Outer, ditto	6	253	One 80 0 0	
Flamborough, ditto	21	860	Two 70 0 0 ea.	50 0 0
Foulness, ditto	{ 30 since } { 1st July, 1833. }	860	Two { 55 0 0 } { 45 0 0 }	30 0 0
Portland, High, ditto	21	863	Two { 80 15 0 } { 45 10 0 }	30 0 0
Caskets, ditto	24	1,064	{ One and } { family. }	80 0 0
Scilly, ditto	30	1,296	Two { 52 10 0 } { 101 13 5 }	56 5 0
Beachy Head, ditto	30	1,320	One 100 0 0	40 0 0
South Stack, ditto	21 and 3 added.	760	Two 75 0 0 ea.	105 0 0
Fern Leading, fixed	1	{ Included with } { Fern, Inner. }	One 35 0 0	{ Included in } { that for the } { Fern Inner } { and Outer. }
Haisborough, High, ditto . .	11	479	One 65 0 0	50 0 0
Haisborough, Low, ditto . . .	11	438	One 95 0 0	
Lowestoft, High, ditto	11	593	One 65 0 0	
Lowestoft, Low, ditto	3	173	One 65 0 0	30 0 0
Pakefield, ditto	1	64	One 65 0 0	
Needles, ditto	10	493	One 76 10 0	
Hurst, High, ditto	3	174	One 72 10 0	50 0 0
Hurst, Low, ditto	4	232	One 72 10 0	

Manufac-
tures.

TABLE continued.

Name of Light and Description.	Number of Burners.	Annual Consumption of Oil.	Number of Keepers, and Salaries and Allowances.	Salaries to Agents.
		Gallons.	£. s. d.	£. s. d.
Portland, Low, fixed	15	661	One 80 15 0	Included with the Portland High.
Eddystone, ditto	24	1,107	Four { one 42 0 0 three 30 0 0 each. 200 12 3	80 0 0
Lizard, Eastern, ditto	19	846	One 85 0 0	50 0 0
Lizard, Western, ditto	19	846	One 75 0 0	50 0 0
Bideford, ditto	2	68	Two 74 4 0 each.	30 0 0
Flatholm, ditto	14	645	One 80 0 0	50 0 0
Usk, ditto	4	202	One 70 0 0	40 0 0
Milford, High, ditto	11	525	One 56 6 0	80 0 0
Milford, Low, ditto	16	697	One 56 6 0	80 0 0
Air, ditto	9	384	Two 35 0 0 each.	30 0 0
St. Bees, ditto	9	477	One 50 0 0	30 0 0
Caldy, ditto	10	495	One 60 0 0	40 0 0
North Foreland, ditto	18	864	Two 40 0 0 each.	40 0 0
South Foreland, Low, ditto	15	827	Two 40 0 0 each.	40 0 0
South Foreland, High, ditto	15	803	Two 40 0 0 each.	40 0 0
Burnham, Low, ditto	2	{ Included in the consumption of the High light. }	One 0 12 0 per wk.	{ Included in that for the High light. }
Nash, East, ditto	13	560	One 65 0 0	40 0 0
Nash, West, ditto	12	560	One 65 0 0	40 0 0
Lundy, revolving and fixed	13	603	Two 80 0 0 each.	80 0 0
Bardsey, ditto	15	616	One 100 0 0	80 0 0
Burnham, High, intermittent	4	{ 249 including the consumption of the Low light. }	One 65 0 0	20 0 0

Light Vessels belonging to the Corporation.

Name of Light and Description.	Number of Burners.	Annual Consumption of Oil.	Tonnage of Vessel.	Number of the Crew, Wages, and Allowance.			Salaries to Agents.
		Gallons.					£. s. d.
Spurn, Floating	8	202	149	{ 1 Master, £5 per Month. £20 House-rent. }	1 Mate, £4 per Month.	9 Seamen, 50s. and 45s. per Month. }	80 0 0
Dudgeon, ditto	8	445	131	ditto	ditto	10 ditto	60 0 0
Lynn Well, ditto	16	342	103	ditto	ditto	8 ditto	30 0 0
North Haisborough, ditto	16	400	152	ditto	ditto	10 ditto and boy	30 0 0
Newarp, ditto	24	542	145	ditto	ditto	9 ditto	80 0 0
Stanford, ditto	12	248	80	ditto	ditto	7 ditto	80 0 0
Sunk, ditto	8	222	125	ditto	ditto	10 ditto and boy	100 0 0
Nore, ditto	8	199	100	ditto	ditto	3 ditto and boy	30 0 0
Galloper, ditto	16	364	129	ditto	ditto	10 ditto and boy	40 0 0
Goodwin, ditto	24	495	179	ditto	ditto	10 ditto and boy	40 0 0
Gull, ditto	12	254	90	ditto	ditto	6 ditto and boy	40 0 0
Owers, ditto	8	252	90	ditto	ditto	9 ditto	40 0 0
South Sand Head, ditto	8	229	156	ditto	ditto	10 ditto and boy	30 0 0

Manufactures.

Mechanical Processes.

Lighthouses under the Management of the Corporation.						
Name of Light and Description.	Number of Burners.	Annual Consumption of Oil.	Number of Keepers, and Salaries and Allowances.		Salaries to Agents.	
		Gallons.		£.	£. s. d.	
Heligoland, fixed	24	1,010	two {	70 50	Local At London	40 0 0 40 0 0
Longships, ditto.	19	938	four {	30 each. 102 per annum.	Local At London	30 0 0 10 10 0 30 0 0
Light Vessels under the Management of the Corporation.						
Name of Light and Description.	Number of Burners.	Annual Consumption of Oil.	Tonnage of Vessel.	Number of the Crew, Wages, and Allowance.		Salaries to Agents.
		Gallons.				£.
Bembridge, floating	6	240	132	1 Master, £5 per Month. £20 House-rent.	1 Mate, £4 per Month.	6 Seamen, 50s. and 45s. per Month.
						Local 40 At London 40

Amount of revenue.

(839.) In other Tables given in the Report the amount of revenue derived from the several lights is given, and the charges thereon, the surplus and other particulars; not only in those under the management of the Trinity Board, but also of private persons, the Commissioners for the Northern Lighthouses, and the Ballast Board, of which the following is an abstract.

No. of Lights.	By whom held.	Gross Collections.	Charges of Collection.	Expense of Maintenance.	Net Surplus.
		£	£	£	£
55	Trinity House . . .	83,041	6,670	35,904	40,467
14	Private Individuals	79,676	10,244	9,109	60,322
25	Commissioners of Northern Lights	35,526	3,261	11,314	20,051
40	Commissioners of Ballast Board, Ireland	42,061	1,960	18,505	21,596
134		240,304	22,135	74,832	142,436

Appropriation of the revenue.

(840.) Referring only to the Trinity Board, it appears that after defraying the necessary expenses, a large surplus annually accrues to the Corporation of the Trinity House out of the rates collected from the shipping for the support of the Lighthouses. A considerable portion of this surplus is devoted to charitable objects, the promotion of which is deemed by the Board one of the duties imposed on them by their Charter. A question has, however, arisen whether dues can be levied on shipping for any other purpose than that of supporting the Lighthouses, &c. The General Shipowner's Society in London, the Chamber of Commerce in Greenock, and others, object to such large sums being applied to charity, and call for relief to the shipping by a reduction of dues. Select Committees of the House of Commons, in the years 1822 and 1824, recommended to the Brethren of the Trinity House to reduce their expenditure for charitable purposes, and to lessen the amount of the imposts and restrictions on the shipping. But the Brethren have

not deemed it their duty to attend to these suggestions; for in the year 1820 their expenditure on the almshouses and pensioners of the Trinity House amounted to £32,035, and in 1832 to £32,861. The present Committee are, however, strongly impressed with the justice of limiting the charges upon shipping, in every case, to the purpose for which the charges are sanctioned, whether by Patent or Act of Parliament; and if there should be a surplus, that a reduction in the amount of these, and all other rates, should be made equal to the whole surplus. No objection is made by the Committee to the present mode of appointing the objects of charity, or to the manner in which the bounty is dispensed; the objection is to the *principle* of taxing the shipping for any other purpose than that of supporting the Lighthouses. The Select Committee on Foreign Trade in 1822 questioned the right as well as propriety of applying the surplus light dues to the purposes of charity; and in examining into the 36th of Elizabeth and the Charter of James II., by which the Trinity dues are regulated, they reported, that "no specific appropriation of these dues is to be found, except what may be collected from the 62d section of the last-mentioned Charter, which directs the application of moneys received by decrees, orders, agreements, fines, forfeitures, or otherwise, to the repairing of the Trinity almshouses and the relief of poor Brethren and their wives, and poor seafaring men." The charge made on foreign ships, it is stated, does not appear to be authorized by any Act, Charter, or Patent; and the amount on British shipping exceeds considerably the rate sanctioned by the Charter under which it is collected.

"It may even be conceded," the Committee observes, "that the surplus dues from the buoys and beacons, and the rent of land, might be applied to charity; but if the whole surplus from all these sources be applied to pay a just proportion or share of the expenses of the salaries of the Elder Brethren, and of the office establishment, there will be no surplus whatever for such charitable purposes."

On a review of the evidence relative to the right of the

Manufac-
tures.

Trinity House to retain a surplus arising from the light dues for the purpose of being applied to charitable objects, the Committee, after mature consideration, and referring to the Reports of the Select Committees of 1822 and 1824, recommend that all pensions and charitable allowances now paid by the Trinity Corporation from the surplus of the light dues under their management (except to servants and others belonging to the lighthouse establishment) shall cease with the lives of the individuals now on the pension list, so far as the same may be legally done; and that from and after this time no new pensions, save as above excepted, shall be admitted on, or paid out of the surplus of the Lighthouse dues." And in the event of the Trinity House Brethren not deeming it to be their duty to attend to this recommendation, it is stated that "it is in the power of his Majesty in Council, by the 3d Geo. IV. c. 3, to require a reduction in the rates, prices, dues, duties, or tolls, imposed or granted by any Charter or Act of Parliament to the Trinity House;" "and if the Board," it is added, "should persist in applying the surplus light dues to charitable purposes after the House shall have decided to adopt the recommendation of your Committee, it will be easy for his Majesty in Council to require the Board to reduce the dues on each or on all these sources of income, until the Trinity Board shall not have any surplus to apply."

In order to form a correct opinion of the reduction that might have been made, or may now be, the following comparison is given of the clear income and expenditure of the Trinity House in two different years:—

	1820.	1832.
Amount of surplus for general purposes, arising out of light dues. .	£51,561	£40,467
Surplus of buoyage and beaconage. .	2,769	3,643
Net profits of ballastage	1,962	2,185
Interest on stock in the public funds	6,960	4,781
Rents of estates for charitable uses.	2,316	3,797
	£65,568	£54,873
Expended on almshouses and pensioners	£32,035	£32,861
For salaries, office expenses, &c. . .	12,149	16,725
For new lighthouses, &c.	15,223	21,868
Cash vested in public stock	2,000	
	£61,407	£71,454
Balance in hand	£4,161	
Excess of expenditure		£16,581

The excess of expenditure in 1832 was augmented by the purchase of the North Foreland lights.

The Trinity House have at present a sum amounting to £155,873, arising from the surplus dues of former years, invested in the public stocks, yielding a yearly interest or dividend of £4676, applicable to the general purposes of the Corporation, and exclusive of those sums which are invested for particular charitable purposes under the management of the Board. Though the Brethren declined to attend to the recommendation of the previous Committees, and have intimated to the present Committee that the same disposition still prevails, "and that they are not disposed to reduce the charity they now dispense," they have reduced the rates formerly charged on all shipping for the objects of their institution. Since January, 1823, "one penny per ton has been charged on British oversea traders, and on

foreign privileged vessels entering the port of London, instead of eightpence formerly charged; and foreign vessels not privileged have been reduced from eightpence to twopence per ton." The benefit of this reduction may be estimated by the fact, that the toll levied on the shipping in 1832 for 55 lights was less by £7998 than the toll levied in 1820 for 33 lights.

(841.) Such being the great revenue derived from the lighthouses of Great Britain, it is very desirable that every aid that Science can afford should be had recourse to, in order to render the system the most perfect and efficacious possible; and it is admitted by the Committee that every readiness has always been shown by the Trinity Board to effect this great object. Accordingly, numerous experiments have been made with gas of different kind, with lenses, and by other means, on which most interesting information is given in the Report and in the Minutes of Evidence. Of these, the first question is the nature of the light. It is not many years since the lights were produced merely by coal fires, unaided by any optical or other means; then were substituted tallow or wax candles, also unaided by reflectors or otherwise. At length, Argand invented his celebrated burners; these were soon after employed with parabolic reflectors, placed behind to reflect the light; and many lights were substituted for one larger, because the reflector of course intercepted all the light, except that falling on its reflecting surface. This is now the light generally adopted; and although it is very desirable to increase the focal light, there is perhaps no other Mechanical or Optical arrangement so well suited for the purpose. The reflectors at present used have certainly not the most perfect surface, as they consist only of copper plated, and their curvature is given only by the coppersmith's hammer, or by some similar means; they, therefore, are necessarily but imperfect reflectors, and probably do not throw back more than one-third the light falling upon them; but on the other hand they intercept a large portion of the sphere of radiating light from the burner, probably three-fourths of the whole, and, if so, three-fourths of one-third of the entire light, or one-fourth of the whole is projected in the line or cone of reflection.

The quantity of light, however, absorbed by the reflector has been thought objectionable, and this led in one or two cases to the application of a lens on the principle of refraction. But here two sources of loss were substituted for one. The portion of the radiating sphere of rays, intercepted by the lens, was scarcely one-twentieth of that intercepted by the reflector; and, moreover, the thickness of glass absorbed a great portion of the light that fell upon the refracting surface; so that upon the whole such a light was very inferior to the former.

This latter objection was obviated by an ingenious suggestion of Sir David Brewster, which consisted in forming what he calls a polyzonal lens. Instead of a large solid lens of 3 feet diameter and 3 feet focus, in one mass, he suggested the idea of building one of the same dimensions in several segments, preserving the refracting surfaces, but avoiding the thicknesses on the central parts. The lens, a section of which is shown in plate lvi. fig. 7, 8, was executed by Mr. William Gilbert, optician, Leadenhall-street, London, and on several occasions the writer of this Paper had opportunities of witnessing its effect, both with the maker individually, and with the Elder Brethren of the Trinity House.

Mechanical
Processes.

Experi-
ments on
the most
effective
modes of
lighting.

Parabolic
reflectors.

Refracting
lens.

Manufactures.

Drummond's light.

Subsequently, a much more elegant and effective means of lighting was suggested by Lieutenant Drummond, of the Royal Engineers, which consists in the combustion of streams of oxygen and hydrogen on a ball of lime placed in the focus of a common parabolic reflector, the light from which is so intense as to cast a shadow on the ground at the distance of 12 or 15 miles; being equivalent in power to 240 Argand burners. A particular description of this light and apparatus is given in the *Philosophical Transactions* for 1830, from which, and from the Minutes of Evidence, above quoted, we shall select a few particulars; only observing that, at a trial of the effects of the three lights in one of the long storehouses in the Tower, the writer was present, and he cannot better state the comparative effect of the three on his mind than by saying, that supposing Lieutenant Drummond's light to be the sun, Sir D. Brewster's lens was comparatively the moon, and the common reflector and Argand burner a watchman's lantern. On these comparative effects, however, the Report has entered at some length, and we cannot do better than give it in the language of the reporter.

Parliamentary Report. Lieutenant Drummond's evidence.

(842.) Lieutenant Drummond, being requested to state to the Committee the result of his observations on the different modes of lighting Lighthouses, replied, that "the mode now in use in this Country consists in placing the common Argand burner in the focus of a parabolic reflector. This instrument is made of silver, strengthened with copper; it is about 3 or 4 inches in focal length, 21 inches in diameter, and is in general use in the Lighthouses of the United Kingdom; the number and arrangement of the reflectors in each Lighthouse depend on the light being fixed or revolving, and upon other circumstances connected with the situation and importance of the Lighthouse. The mode adopted in France consists in placing a large Argand lamp, having four concentric wicks, and giving a very powerful light, in the centre of the building, and around it a series of glass lenses of a peculiar construction; using in this case a refracting instead of a reflecting instrument, to collect the light, and only one lamp instead of a number. The lens is a very beautiful instrument; it is about 30 inches square, plano-convex, and formed of separate rings or zones, whose common surfaces preserve nearly the same curvature as if they constituted portions of one complete lens, the interior and useless part of the glass being removed. To form a lens of such magnitude out of one piece of glass would scarcely be possible, and, if it were so, the thickness of the glass would materially obstruct the light. The merit of the invention consists in building it of separate rings. The priority of the suggestion is due to Dr. Brewster; MM. Arago and Fresnel subsequently proposed the same plan, manifestly without the knowledge of what Dr. Brewster had done; and they were the first who got such a lens constructed, and who showed, that when used with the powerful lamp alluded to, it might be applied with great advantage and effect to the illumination of Lighthouses."

Examination continued.—"What is your opinion on the relative merits of the two modes which you have stated?—The light given by the lens was found by our experiments at the Trinity House, in London, to be equal to that of 9 common reflectors.

"One lens?—Yes; the light of one lens equal to the light of nine reflectors. Then there is some additional apparatus described in the Memoir of Fresnel, and used

at the Carduan Lighthouse, but which we did not possess, which is said to increase the light so that it may be taken to be about equal to the light of 10 reflectors.

Mechanical Processes.

"That is, an increase of one light?—Yes.

"What is the nature of that additional apparatus, by means of which this additional light is obtained?—The nature of the apparatus is this: that portion of the light of the lamp which escapes the lens placed in front of it is caught by another and smaller lens placed above it, and then again reflected in a horizontal line parallel to the beam of the original lens.

"Then it appears to be a small additional lens, a refractor to throw the light back on the lens?—It is rather difficult to explain this without a diagram. This additional refractor would throw the light which it collects in a beam diverging from that of the first or primary lens: this secondary beam must, therefore, be again bent down and thrown in the direction of the first beam; this is effected by plane reflectors. The escape of all that light which passes above the primary lens is thus prevented, but its brilliancy is considerably diminished by the complexity of the reflecting and refracting apparatus; it may, however, be considered as contributing, in the proportion already stated, to the original light; and, therefore, one of these lenses, with the apparatus complete, as used in the French Lighthouse, may be considered, according to our experiments, equal to 10 of the common reflectors.

"What is the comparative expense of oil between the two?—The result of our experiment was, that the French lamp consumed as much oil as, I think, 17 lamps.

"One of the French lamps?—Yes.

"Consumed as much as 17 Argand lamps?—Yes; and that I think is very nearly the same result which MM. Fresnel and Arago have given; but I state this from memory.

"Giving the light of only ten?—Yes.

"Then, if the consumption of oil in the Carduan Lighthouse is as 17 to produce the light of only 10, wherein is the advantage of using such lamps in preference to the plain burners?—I stated that the lamp was placed in the centre of the building, and the lenses placed round it; each of the lenses occupies a portion of the circle equal to 45 degrees; so that eight such lenses may be placed round the lamp to complete the circle. In an English Lighthouse of the first order, take Beachy Head for example, the most recent, and justly considered one of the best, there are 10 reflectors on each side, and there are three sides illuminated; so that there are 30 reflectors in all, and of course 30 lamps. By a consumption of oil, therefore, equivalent to that of 17 common lamps, an effect is produced in the French Lighthouse equal to that which is produced in the English Lighthouse by the consumption of 30 such lamps.

"That is, one French lamp, applied in that manner, will give you the same light at the expense of 17, which the 30 reflectors do at the expense of 30?—Yes.

"And the light would be total in the one case, whereas the other is only on three sides?—In the one case you have three sides, and in the other case you have eight sides illuminated. But there is a circumstance, not unfrequently overlooked, which must here be taken into consideration, and that is the divergence of the light, which is different in the two cases. In the

Manufac-
tures.

common parabolic reflector the divergence is equal to about 17 degrees; in the French lens it is equal to rather more than 5 degrees; so that in the English Lighthouse 3 times 17 degrees will be the total illuminated portion in one revolution, and 8 times 6 will be the illuminated portion in the French during the revolution.

"Then are the Committee to understand that the light from the French lamp diverging only 5 degrees is much more intense than when by the English reflector it diverges 17, and, consequently, will be much better seen, although perhaps not so long?—When both are directly opposite to the spectator, he would not be able to distinguish any difference between the 10 reflectors and the French lamp, but the period during which each side would be visible would be greater in the English than in the French. It will be recollected, however, that in the French there are eight sides illuminated, whereas there are but three in the English.

"In short, the English illuminates more of the sea?—Yes; comparing with the side. During one revolution, say of seven minutes, there would be in the English Lighthouse three equal periods of light, each lasting 20 seconds, separated by equal intervals of darkness, each lasting 120 seconds. In the French, eight periods of light, lasting each about 6 seconds, with intervals of darkness, each lasting about 46 seconds."

Drum-
mond's
light and
apparatus.

Pl. lvi.
Fig. 1—6.

(843.) *Drummond's light and apparatus.*—We proceed now to explain the apparatus employed by Lieutenant Drummond for fitting his light to the purposes of the Lighthouse, taking our description from the *Philosophical Transactions* for 1830. In our plate, (marked lvi.) fig. 1. represents the lamp. The two gases, oxygen and hydrogen, proceeding from separate gasometers, enter at *o* and *h*, but do not mix till they arrive at the small chamber *c*, of which fig. 2 is a section: into this chamber the oxygen gas from the inner tube is projecting horizontally through a series of very small apertures, and the hydrogen gas rises vertically through a series of similar apertures at *d*. The united gases then pass through two or three pieces of wire gauze placed at *e*, and, being thus thoroughly mixed, issue through the two jets against the ball *b*. To prevent the wasting of the ball opposite the two jets, and at the same time to diffuse the heat more equally, it is made to revolve once in a minute, by means of a movement placed underneath the plate *m*, and with that the wire *f*, carrying the ball and passing through the stem, is connected. Notwithstanding, however, this arrangement, the effect of the heat is such as gradually to cut a deep groove in the ball, so that at the end of about 45 minutes it becomes necessary to change it. In a Lighthouse, where it is of essential consequence to maintain a constant light, it would be unsafe to intrust this to an attendant, and hence the necessity of devising some means for remedying this inconvenience. The apparatus represented by fig. 3 is designed for this purpose, and is drawn in the manner in which it is applied to a reflector, the dotted outline of which is shown.

The wire *a b* passes through the focus of the reflector, and upon it are placed the number of balls, at *A*, required for any given time; these, by means of the shears *s*, as shown in fig. 4, are admitted between the plates *p p*, and hence permitted to fall in succession to the focus. No. 1 represents the focal ball; about two minutes before the change, the ball 3 falls into the position 2, where it becomes gradually heated. At the end of that

time the curved support *t*, moving on a pivot, is thrown into the position represented by the dotted line, by the momentary descent of the ring *r*, which, receiving an impulse from the weight *w*, acts upon the extremity *u* of the support. No. 1 falls, but it is prevented from descending more than its own diameter by the loop *l*, and No. 2, following it, occupies the focus. The support *t*, being immediately released, returns by the action of a spring to its former position, retains No. 2, and suffers No. 1 to escape through the loop into the cistern.

The wire *a b* and the support *t* revolve together, and carry round the focal ball, which is ignited as in fig. 1 by the two jets *z z*. These jets, which are movable round the joints *d d*, enter through small apertures cut in the sides of the reflector, and are easily adjusted to the proper distance from the ball.

Wherever the light is required to be diffused equally round, the renewal of the lime may be effected still more easily, by using a cylinder, as represented in fig. 5, instead of a ball, which, being gradually raised while revolving, brings fresh portions in succession opposite the jets. In a reflector a cylinder occasions partial shadows at the top and bottom; still, however, the simplicity and certainty with which it may be renewed will probably entitle it to a preference even in this case.

These different instruments were prepared by Mr. Simms, of Fleet-street, to whom, for various ingenious suggestions, for the trouble which he has bestowed upon them, and the assistance which he contributed during the progress of the experiments, Lieutenant Drummond expresses himself greatly indebted.

The apparatus for supplying the lamps with gas is represented in fig. 6. It consists of two strong cylinders *A*, three feet high, the one for oxygen, the other for hydrogen: the gas is compressed two or three times in each, the latter by being generated under pressure, the former by being pumped in. To each of these gas-holders a governor, *B*, is attached, of one of which a section is shown; by which means, whatever be the variation of pressure in the gas-holder, provided it exceed that of the governor, the gas will issue at *x* with a uniform and constant stream; in the present instance under a pressure of 30 inches of water. Although this apparatus was of great use in the experiments at the Trinity House, and subsequently at Purfleet, by enabling the experimenters to keep within a small compass a supply of gas sufficient for two hours' consumption, and even to renew it without impeding the progress of the experiments, yet it may be remarked, that on a large scale the gasometers required would be much more simple, since compression would no longer be required. This apparatus was made by Mr. Samuel Crosley, the ingenious inventor of the gas governor.

"Our first experiments were on the illuminating powers of the different lights independently of the lenses or reflectors with which they are generally used. The method of shadows and that of equally illuminated surfaces, both depending on the same principle, but requiring different instruments, were employed, the former after the manner of, and with all the precautions recommended by Count Rumford; the latter according to the arrangements proposed by Dr. Ritchie, who was kind enough on this occasion to make several experiments with his own instruments, and without being made acquainted with the results previously obtained by us. The standard we used was an excellent Argand lamp

Mechanical
Processes.

Compara-
tive experi-
ments.

Manufactures.

$\frac{7}{8}$ inch in diameter, supplied with the finest spermaceti oil, and capable of supporting a flame $1\frac{1}{4}$ inch in height. The following results were obtained.

		Stand- ard.	Wax candle $1\frac{1}{2}$ in diam- eter, the wick consisting of 40 threads.
Mean of	5 observations by shadows...	1	= 9.1
French lamp	9 ditto	8.7	
	6 ditto by illuminated surfaces	12.1	10.4 = 94.6
Oil gas burner same diam. as standard	4 ditto by shadows.....	0.95	= 8.7
Lime-ball or cylinder $\frac{3}{4}$ inch dia- meter	2 ditto	9.2	
	2 ditto	10.4	
	4 ditto by illuminated surfaces	18.6	13.5 = 122.9
	10 ditto	16.9	

"The light of the ball depending upon the intensity of the heat is very different at different parts, being greatest opposite the jets, and diminishing towards the sides. The mean of the greatest and least intensity is taken in the above Table: and, moreover, though the greater number of observations might appear to warrant giving greater weight to their results, yet being made on the same day, and under the same circumstances, it was found that the results seldom differed, whatever might be the number of observations; hence the arithmetical mean is taken, and we obtain this remarkable result, that the light emitted by a lime-ball only $\frac{3}{8}$ of an inch in diameter, heated by two jets, is equal to 13 Argand lamps.

"With respect to the intensity or intrinsic brightness of the different lights, the property on which their utility in Lighthouses more immediately depends, we have the following results:

"The intensity of

	Mean.	
French lamp, mean 11 observations by shadows = 4.1		
French lamp, mean 8 ditto = 3.8	4.0	times in
Oil gas 6 ditto = 0.85		the inten-
Lime 6 ditto = 263.9		sity of the
Ditto 3 by illuminated surfaces.. = 264.4	264.1	standard.

"These results were obtained by screening the different lights, and then placing equal apertures opposite each, changing the apertures and taking the mean to destroy the effect of any inaccuracy in size. The intensity of the lime-ball being therefore 264 times that of the Argand lamp, a single reflector illuminated by the former will be equal to 264 reflectors illuminated by the latter; but the divergence of the reflected light, depending upon the size of the luminous body in the focus, will be smaller with the ball than with the lamp in the proportion of about 3 to 8: hence in such a Lighthouse as that of Beachy Head, 8 reflectors may be substituted for 30, and yet an effect would be produced 26 times greater than that of the present light, the most perfect of its kind in this Country.

"By similar experiments it was found that the French lens was equal to 9.1 reflectors; and if the effect of the additional lenses and reflectors which ought to accompany it, and which has been estimated at one-seventh, be added, then the lens is equal to 10.4 reflectors. In like manner, therefore, the effect of a single reflector with a lime-ball would be equal to 25 times that of such combination of lenses.

"Such appear to be the singular and important results of our late experiments at the Trinity House. Made as they have been with every precaution, by different individuals, with different instruments, and unbiassed by the knowledge of each other's results, I see no reason to

doubt their accuracy; and the comparative appearances of these lights, when exhibited at a distance of ten miles, to which I shall presently allude, though not admitting of being reduced to numbers, confirm the striking superiority of this method of illumination.

"It may now perhaps be asked, at what expense can such a light be maintained? can the gases by which the requisite heat is produced be procured at such a price as to compete with oil or coal gas? The data I possess for forming an estimate of the expense of the gases are very scanty, but the quantity consumed was accurately determined; at the same time the consumption of the other lights was also tried, and the results are as follows:

	Consumption in $3\frac{1}{4}$ hours.	Expense per hour.
An Argand lamp seven-eighths of an inch in diameter	1 gill	0.69 penny
The same placed in a reflector. .	$1\frac{1}{2}$ gill.	0.83 penny
The French lamp	2 qts. $\frac{1}{2}$ pt. 1s. $2\frac{1}{2}$ d.	

"The lime required 4 cubic feet of hydrogen, and 2 of oxygen per hour, and the probable expense is 5d. per hour.

"In a revolving light of the first class, containing 30 reflectors, the expense per hour would therefore be about 2s. 1d. If the French method were employed, the increase of light would be $\frac{1}{10}$ th, and the expense only 1s. $2\frac{1}{2}$ d. per hour. If six reflectors illuminated with lime-balls were used, which would probably be sufficient, the probable expense would be 2s. 6d. per hour, and the increase of light 26 times.

"If this estimate be erroneous, I think it will prove to be so in excess; admitting, however, that the expense should in the first instance somewhat exceed what has been stated, it may in this as in every similar instance be expected, that after a little experience, considerable reduction would be effected. This is a new source of artificial light, differing from every other at present in use, and the materials by which it is produced are among the most abundant products of nature; but, never having yet been applied on a great scale to any practical purpose, it has not hitherto been an object to obtain them in a separate state at a small expense. When this is effected, it will no doubt receive many useful and important practical applications.

"Meanwhile, however, the case in question may perhaps be regarded as one in which expense ought not to be a primary object of consideration. On all ordinary occasions, the preference of one mode of illumination to another is a question of convenience, luxury, or economy; but in this it assumes a more important character, for it involves to a great extent the preservation of life and property."

To complete the preceding account, it only remains to add a description of the appearances presented by the different lights when exhibited at a distance; and, to those who have entered with any degree of interest into the above details, such a description, it is hoped, cannot fail of proving acceptable.

The experiments at the Trinity House being concluded, the whole of the apparatus was removed to Purfleet, where on a knoll of chalk about 100 feet above the river a temporary Lighthouse had been erected, and, being fitted with the requisite Machinery, the different lights were made to revolve in succession, and the appearance which they presented, as well as the duration of the light, were observed from the Trinity House at Blackwall, a distance in a straight line of $10\frac{1}{4}$ miles

Mechanical
Processes.Expense
of the
light.Experi-
ments con-
tinued.

Manufac-
tures.

The four faces of the revolving Machine were thus occupied:

No. 1. A single reflector 21 inches diameter, 3 inches focal distance, with an Argand lamp.

No. 2. Seven reflectors with ditto.

No. 3. French lens, with its lamp.

No. 4. Single reflector with lime-ball.

The respective lights were accurately placed in focus. On the evening of the 10th of May, the Machine performed one revolution in eight minutes. Captain Pelly of the Trinity House made the following observations on the different lights from the Trinity House wharf, Blackwall, 10½ miles distant.

No.	Duration.		Divergence.	Computed maximum Divergence.
	min.	sec.		
1	0	25	17.40	17.81
2	0	25	17.40	17.81
3	0	7	5.17	5.18
4	0	9	6.12	6.7

When No. 4, the reflector lighted with the lime-ball, was turned towards the wharf, the light was so great that the shadow of the hand and fingers was distinctly visible even on a dark brick wall, while no such effect was discernible when the other lights were turned in the same direction.

In order more justly to estimate their comparative effects, No. 4 was removed to a temporary tent about twenty-five yards to the right of the Lighthouse, as far as the edge of the cliff would permit, and, on the evening of the 25th and 31st of May, regular series of experiments were made. The inventor being engaged at Purfleet, directing these exhibitions, had not an opportunity of witnessing their effects at Blackwall; but Captain Basil Hall, R. N., who, from the interest which he took in these experiments, was an attentive observer of all that occurred, kindly favoured him with the following interesting account:

"4, St. James's Place, 1st June, 1830.

"MY DEAR SIR,

Letter from
Captain
Basil Hall
to Lieute-
nant Drum-
mond.

(844.) "You wished me to take particular notice of last night's experiments with the different kinds of lights exhibited at Purfleet, and observed at the Trinity House wharf, Blackwall; but I have little to add to what I told you respecting those on the evening of the 25th instant; indeed it is not within the compass of language to describe accurately the details of such experiments, for it is by ocular evidence alone that their merits can be understood.

"Essentially, the experiments of last evening were the same as those of the 25th, and their effects likewise. The degrees of darkness in the evening, however, were so different, that some particular results were not the same. The moon last night, being nine or ten days old, lighted up the clouds so much, that, even when the moon herself was hid, there was light enough to overpower any shed upon the spot where we stood by your distant illumination; whereas on the 25th, when the night was much darker, the light cast from the temporary Light-

house at Purfleet, in which your apparatus was fixed, was so great that a distinct shadow was thrown upon the wall by any object interposed. Not the slightest trace of any shadow, however, could be perceived when your light was extinguished, and any of the other lights were exposed in its place.

"In like manner, on the evening of the 25th, it was remarked by all the party at the Trinity wharf, that, in whatever direction your light was turned, an immense coma, or tail of rays, similar to that produced by a beam of sun-light in a dusty room, but extending several miles in length, was seen to stream off from the spot where we knew the light to be placed, although, owing to the reflector being turned too much on one side, the light itself was not visible.

"Now, last night, there was none of this singular appearance visible; but whether this was caused by the presence of moon-light, or by the absence of the haze and drizzling rain which fell during the evening of the 25th, I cannot say. I had hoped that the appearance alluded to was to prove a constant accompaniment to your light, in which case it might, perhaps, have been turned to account for the purposes of Lighthouses. If in hazy or foggy weather this curious effect of reflected light from the atmosphere be constant, it may help to point out the position of Lighthouses, even when the distance of the observer is so great that the curvature of the Earth shall render it impossible for him to see the light itself.

"The following experiments tried last night were the same as those of the 25th, and certainly no comparative trials could be more fairly arranged.

"*Experiment 1.*—The first light exposed was the single Argand burner with a reflector. This was quite distinctly seen, and all the party admitted it to be a good light; after several minutes this was put out.

"*Experiment 2.*—The seven Argand burners were next shown, each in its reflector; and this was manifestly superior to the first, but how much so I cannot say, perhaps four times as conspicuous. Both these lights had an obvious tinge of brown or orange.

"*Experiment 3.*—The third light which was exposed (on the seven Argands being put out) was that behind the French lens; and I think it was generally admitted by the party present, that this light was whiter and more intense than that from the seven Argands, though the size appeared very much the same.

"*Experiment 4.*—The fourth light was that which you have devised, and which, instead of the clumsy word 'lime,' ought to bear the name of its discoverer. The Drummond light, then, the instant it was uncovered, elicited a shout of admiration from the whole party, as being something much more brilliant than we had looked for. The light was not only more vivid and conspicuous, but was peculiarly remarkable from its exquisite whiteness. Indeed there seems no great presumption in comparing its splendour to that of the sun; for I am not sure that the eye would be able to look at a disc of such light, if its diameter were made to subtend half a degree.

"The next series of experiments was the most interesting and decisive of all. Each of the lights above enumerated, viz. the single Argand burner, the seven Argands, and the French lens, were exposed, one at a time, in company with your light, in order to try their relative brilliancy.

"*First comparative experiment.*—The single Argand

Mechanical
Processes.

Manufac-
tures.

burner was first exposed to this comparative ordeal, and nothing could be more pitiable than the figure it cut; many of the party could not see the Argand light at all, while others could just detect it 'away in a corner,' as some one described it. It was also of a dusky orange tinge, while your light was of the most intense whiteness.

"*Second comparative experiment.*—The seven Argand burners were now substituted in place of the single light. All the party could now see both lights, but the superiority was not less obvious; I really cannot affix a proportion either as to size or brilliancy, but I should not hesitate to say that your light was at least six or eight times as conspicuous, while in brilliancy, or purity, or intensity of light, (for I know not precisely what word to use to describe the extreme whiteness,) the superiority was even more remarkable. All this which I have been describing was expressed, and appeared to be quite as strongly felt by the rest of the company, to the number, I should suppose, of five and twenty or thirty persons, who were all closely on the watch.

"*Third comparative experiment.*—The next comparative trial was between the French lens and your light. The superiority here was equally undeniable, though the difference in the degree of whiteness was not so remarkable; the French light, however, is so nearly similar to that from the seven Argands, that the comparison of each of them with your light gave nearly the same results, and all equally satisfactory on the score of your discovery.

"*Final experiment.*—The flashes with which the experiment concluded were very striking, and might I think be turned to great account in rendering Lighthouses distinct from one another. The revolutions were not effective, and, as I said before, there was no appearance last night of those enormous comets' tails, which swept the horizon on the night of the 25th, to the wonder of all who beheld them: neither could there be detected the slightest trace of any shadow from the light thrown towards us, and I suspect none will ever be seen, when the moon, whether the night be clouded or not, is of so great a magnitude.

"Such is the best account I can give of what we witnessed; and I need only add that there seemed to be amongst the company but one opinion of the immense superiority of your light over all the others brought into comparison with it.

"I am, &c.

"BASIL HALL."

"The advantage of such a light being fully recognised, attention may now be exclusively directed to remove some of those minor obstacles that might render its use in Lighthouses objectionable; and I have great pleasure in adding that the Trinity Corporation are desirous that every facility in their power should be afforded with a view to effect this object, and that a series of preliminary experiments is accordingly to be carried on at their expense."—*Philosophical Transactions* for 1830.

The results of these experiments, if they have been made, have not at present been published.

Lighting, Warming, and Ventilating Manufactories.

(845.) *Lighting of manufactories.*—This was formerly effected by means of candles or oil lamps; but, since the invention of gas-lights, which were at first wholly

employed for this purpose, most establishments and public buildings have been lighted by coal or oil gas, and it would not, therefore, have been necessary to have had a distinct Section on this subject, but for the sake of describing a new process, lately invented by Mr. Beale, whereby a most powerful illumination is produced from the refuse tar of a gas-house, and, therefore, at a very cheap rate, the expense for one light, equal to $4\frac{1}{2}$ Argand lamps, or to 35 wax candles of nearly an inch in diameter, being but three farthings for eight hours.

The only Works thus lighted at present, we believe, are those of Messrs. Enderby, at East Greenwich, where several processes are carried on, as rope-making, canvass weaving, the reduction of India rubber, &c., and where 35 of these lights are employed, one being at the entrance gate of the rope-walk, at a distance of more than two furlongs from the principal building. We have been favoured with an examination of this illuminating process, which is exceedingly simple and interesting, as will be seen from the following description:

A B C D E F (plate lvi. fig. 9) is an external tin or copper case, having a bottom F C, and below this bottom the space F C B E with a cock at E, the purpose of which will be explained as we proceed: *a b c d* is an internal tin or copper cylinder to contain the fluid tar; H is a handle by which it may be drawn out of the external case to be filled with the fluid at the valve *h*. This valve, of course, closes when the cylinder is withdrawn, by its own weight, and when the vessel is filled the valve is shut by pulling the wire seen passing through it; but when it is placed inverted in the outer case the pressure of the wire against the bottom F C opens the valve, and the fluid distributes itself at the bottom, fills the pipe *p p*, and ascends in the lamp tube to *k l*, the level of the aperture in the valve of the cylinder *a b c d*, where it is sustained by the pressure of the atmosphere on the principle of the bird fountain or the common Argand burner. In this state, if a light be applied to its surface *k l*, a slight lambent flame will be obtained, but scarcely perceptible; *m n* is a small pipe, about one-tenth of an inch in diameter, which is connected at *n* with a pipe passing to an air vessel, in which air is contained under a pressure of $1\frac{1}{2}$ pound per square inch, the compression being produced by a pump attached to a steam-engine or in any other way, and there is a stop-cock at *n*, whereby the pipe may be opened or shut at pleasure. K L is a broad open rim, which encompasses the lamp *k l*, and is adjustable upon it, and M N O P is a brass dome resting on this rim, open at top at O N, having an interior conical part attached, which reaches nearly to the upper edge *k l* of the lamp. This dome, placed as shown in the figure, and the stop-cock at *n* opened and properly adjusted for aperture, the lambent flame, before scarcely visible, is now seen rushing out at the aperture O N in a strong vivid white light, equal, as we have before stated, according to very accurate measurement by Dr. Faraday, to $4\frac{1}{2}$ Argand burners, and, by varying the size of the aperture N O, it may be made equal to 10 or more such burners. The pipe *v v* is to prevent the fluid rising above its level, and any fluid which may thus pass this way is let off at the cock E.

Such is the form of this exceedingly ingenious apparatus, which is at present, in all probability, very far from having attained all the perfection of which it is susceptible, although in its present form it answers its purpose admirably in the Works where it is employed.

Mechanical
Processes.Beale's illu-
minating
process.
Pl. lvi.
Fig. 9.Lighting
manufac-
tories

Manufac-
tures.
Application
of this light
to Light-
houses.

In the preceding Section we have entered at some length into a description of Drummond's light, which is, of course, very much superior to it in its intensity, and, if the latter could be rendered as simple as the circumstances of a Lighthouse require, it would be hopeless to expect any thing which could, by possibility, compete with it: but if, after sufficient experiment, it should unfortunately be found irreducible to the requisite degree of simplicity, there is, perhaps, nothing that presents a greater hope of improving the present system of lighting our Lighthouses than the apparatus we have just described, which, at a great reduction of expense, would increase the present illuminating power tenfold.

The theory of its extraordinary illuminating effect is to us somewhat mysterious, but the fact is undeniable. The pipe which admits the stream of air is, as we have said, but one-tenth of an inch in diameter, but it may be closed to any small quantity less than one-tenth, and, by trial with the cock, the adjustment is made which produces the best effect, which is considerably less than the whole, so that the quantity of air requisite to supply twenty or thirty of such lamps is very inconsiderable. At Messrs. Enderby's the pumping is effected by a small power borrowed from the steam-engine, but in a Lighthouse, if this means was thought inconvenient, various other mechanical means might be had recourse to to keep up the pressure required.

Warming
manufac-
tories.

(846.) *Warming manufactories.*—In the preceding two Sections, and in a subsequent one, we have shown the manner in which a gas, in the one case, and a fluid in the other, is conducted from one general reservoir to be delivered at certain places where its use is required. Heat, which is nearly as essential in some cases as light or water, is in a manner somewhat similar sent from one general focus to be distributed throughout very large buildings or manufactories; and we therefore shall, in connection with the Gas Works and Water Works, treat of the means which have been proposed for warming and ventilating buildings. There is, however, one great line of distinction between this and the above two cases, for in these the gas or water is conducted along pipes impervious to either, whereas heat is unconfined, and radiates and escapes in every foot of its progress; it is necessary, therefore, that the source should be as near as possible to the place of delivery; whereas in the two former cases the distance is no otherwise of consequence except as regards economy.

Any person who has visited our cotton, silk, and flax manufactories in Yorkshire, Lancashire, and in Scotland, would be instantly struck with the impossibility of warming buildings and apartments so extensive with common fire-places, at least, without a great risk of danger from fire, and without great inequality in temperature between those places in the immediate vicinity of the fire and others distant from it; but by the means which we are about to describe, every part is brought to an equal and steady temperature, equally conducive to the health and comfort of the hundreds of children and others employed, and to the perfect execution of the work to be performed. In a spinning establishment the principal occupation of the children is the uniting together the ends of fine cotton, silk, or flax, which break during the process, and it would be impossible for the fingers to feel with sufficient delicacy if the temperature were not preserved at a sufficient height to prevent any sensation of cold, not to mention that, besides this, the material itself works best at a certain temperature.

In proportioning and arranging such an apparatus as is here referred to, however, there is one essential point to be previously considered, *i. e.* ventilation. We may readily, by confining the air within any building, warm that air up to a given temperature, but in this state, after a short time, it would become unwholesome and unfit for respiration.

Mechanical
Processes.

(847.) It appears, from accurate experiment, that a man consumes about 32 cubic inches of oxygen in a minute, which is replaced by an equal bulk of carbonic acid gas from the lungs. Now, the quantity of oxygen in atmospheric air is about one-fifth, hence it follows that the quantity of atmospheric air rendered unfit for supporting either combustion or animal life by one man in one minute, by respiration only, amounts to 160 cubic inches. But a man makes twenty respirations in a minute, and draws in and expels forty inches each time, consequently the total quantity contaminated by passing through the lungs in one minute amounts to 800 inches, or nearly three gallons. But during the same time a man discharges a considerable quantity of vapour from the lungs. Experiments on this subject give results which differ considerably, but it may be taken at six grains per minute at the highest, this quantity being sufficient to saturate 800 inches of air with vapour at the temperature given out in respiration; and it is this vapour mixing with the carbonic acid gas which renders the expelled air lighter than the common air, and by which it rises immediately it is discharged from the lungs, and thereby avoids being again inspired—one of those admirable arrangements of an all-wise and all-powerful Creator, of which we have so many instances, and to which every new philosophical fact that is discovered is adding new examples. Other sources of deterioration of the air of a room may be enumerated; *i. e.* insensible perspiration, the consumption of oxygen by candles, lamps, and other lights, &c., which, taken together, show the absolute necessity of some means of ventilation wherever a number of persons are congregated, and more particularly where artificial warmth is superadded to the natural temperature of such a room or building. And as we have seen that the vapour with the azote, both lighter than common atmospheric air, by their admixture with the carbonic acid gas, although the latter is of itself heavier, become, upon the whole, specifically lighter, the contaminated air will ascend to the top of the building, and, therefore, this is naturally the situation in which the valve or other contrivance should be placed for ventilation.

Ventilation.

When the processes carried on and the number of persons employed are constant, a permanent means of ventilation may be adopted, but if these are variable, the aperture through which the contaminated air escapes should be so arranged that it may be suited to the necessity of the case, by admitting of opening and shutting, or of being partially opened or shut as the case may require.

The apparatus for heating should also be so adjusted that it may always supply such a quantity of heat as is carried off by the hot contaminated air, or the difference of heat between it and that of an equal bulk of common air at the temperature of the atmosphere.

Different means have been recommended and adopted for the warming of buildings: one by steam pipes passing along the rooms; a second, by air heated in pipes and discharged into the building; and a third, by the circulation of hot water through iron pipes, a circulation which is kept up by the hot water having a tendency to

Different
means of
warming.

Manufac-
tures.

ascend by being rendered lighter by expansion, and, after cooling, becoming specifically heavier, so that after circulation the water which has been cooled in the process enters at the bottom of the boiler to be again heated, when it ascends to the top, passes through the pipes, enters again at the bottom, and so continually. We might also mention a mode of drying formerly had recourse to, which was simply effected by an iron stove containing the fire, and pipes for conducting away the smoke and flame which were thus heated, and thus conveyed a close unhealthy degree of heat to the room in which they were placed.

Warming
by steam.
Pl. liv.
Fig. 1.

(848.) *Warming by steam.*—Fig. 1. plate liv. is a section of a silk manufactory, belonging to Messrs. Shute and Co., of London, situated at Watford, Herts, and is described by the late ingenious Mr. Tredgold, in his *Treatise on the Warming and Ventilating Buildings*. The manufactory was formerly heated by thirteen iron stoves, with pipes for the smoke passing out of the windows and through the roof; but, in 1817, the proprietors had the stoves removed, and a steam apparatus put up by Messrs. Bailey, of Holborn, which has been in constant use ever since. The arrangement is very simple. B is the boiler and furnace house outside the building, the smoke being conveyed away through the funnels and chimney G, seen in fig. 1. A is the main steam pipe up which the steam ascends from the upper part of the boiler. Into this first pipe are inserted the longitudinal pipes suspended near the ceiling of each room, marked S S S S; each of these pipes has a valve to regulate the supply of steam, and a siphon at the other extreme, the construction and purpose of which will be described below. C is a small pipe for returning the water of condensation to the boiler from the upper three floors, that collected from the steam pipe of the lower floor being used for washing and other purposes. In order to accumulate the water of condensation the longitudinal pipes, it will be seen, are placed at a slight degree of inclination down towards the pipe C, so that as the water is formed in these pipes, it runs gently down towards the further end, there enters the descending small water pipe C, whence it passes again to the bottom of the boiler, retaining still considerable heat. Mr. Tredgold observes, that the power of making a good arrangement in this case was extremely limited, the mill being already full of Machinery, but the advantages of it are still great, which he thus enumerates: 1. A considerable reduction in the rate of insurance. 2. The absence of all smoke, dust, and ashes, which had been found very injurious to the silk in the former way of warming. 3. A saving of fuel, and of time and labour in attending to the fires. 4. An equable heat instead of the partial one of the stoves, and a regular supply of fresh air into the mill warmed by the main pipe A. 5. The labour proceeds without interruption and in a comfortable temperature. 6. The children are free from chaps and chilblains in the winter season owing to their having warm distilled water for washing. The mill is 106 feet 4 inches by 33 feet; the upper story is 8 feet high, is warmed by a pipe of 3 inches diameter; the next story, 8 feet 8 inches high, is warmed by a pipe of 4 inches; the next, 9 feet high, by a pipe also 4 inches; the next or lower story, 9 feet high, by a pipe of 5 inches diameter. The building is supplied with water from a cistern at W.

Self-acting
siphon.

It remains for us to explain the nature and uses of the siphon above referred to, and not shown in the

figure; this will appear in the course of the following general observations. In every part of the distributing apparatus it is necessary to prevent any considerable quantity of water collecting, for when steam is admitted into the pipes, &c. and meets with a great surface of cold water remaining in them, it condenses the steam so rapidly as to endanger the boiler and pipes, should they not be firm enough to resist the sudden external pressure thus brought upon them. When it is possible to have the boiler at a lower level than the pipes and other steam vessels, it is best to return the water of the condensed steam into the boiler again, because it not only saves fuel, but also requires only a small supply of fresh water, which is an object of some importance in certain situations. It is, however, desirable in some cases to allow the water of condensation to collect in the pipes, and to continue to give out heat after the steam has ceased to flow into the pipes. Stop-cocks may in these cases be employed, and which afterwards allow the water to be educted from the pipes: the same cocks also serve for letting the air out of the pipes when the steam is first admitted, but, when the water is returned into the boiler, the advantage of this supply of heat cannot be reserved; and in these cases a self-acting apparatus is commonly employed for taking off the water of condensation, one kind of which is the siphon above referred to. This is represented in plate liv., fig. 2. The pipes are so fixed that A is the lowest point of a longitudinal pipe; thus any quantity of water that may be formed in the pipe will flow into the siphon A B C at A, and run to waste, or otherwise, at C, the water in the legs of the siphon acting as a trap to the steam in the pipe A. The length of the leg A B of the siphon should not be less than is equivalent to the force of the steam in the pipes, and must, therefore, be determined accordingly. For example, when the steam is worked at the rate of 10 pounds per square inch, the column of water should not be less than ten feet, and even with this pressure there will be considerable oscillations unless a valve be placed somewhere intermediate, as at D. When the legs are both filled with water, and at rest, this valve should be open so as to close whenever the water has a tendency to return into the pipe. The siphon should also be large enough to take away with ease all the water formed by condensation; at the same time it should not be too large, because there would then be a loss of heat in the leg A B, from its being filled with steam; and in all cases the siphon should be carefully protected against freezing. In connection with the siphon it is usual to place a cock for letting the air out of the pipe instead of the stop-cock above referred to; such a one is shown at E, and it is kept to range with the lower part of the pipe, because the air being heavier than steam it will occupy only the lower portion of it.

Mechanical
Processes.

But when it is not convenient to get depth for a siphon, a steam-trap or valve, to open by a float ball, is employed, and Mr. Tredgold thinks most conveniently, as follows: Let B C, fig. 3, be a square box attached to the end A of the steam-pipe, and D a hollow copper cylinder fixed to a conical valve E; then when steam is condensed the square box will fill with water, which will float the hollow cylinder, consequently the water will escape and run by the pipe F into the drain, at all times when the quantity of water in the box is greater than is required to just float the cylinder; and when there is less than will float it the

Fig. 2.

Fig. 3.

Manufac-
turesWarming
by hot
water.Mr. Price's
patent.Pl. liv.
Fig. 4, 5,
6, 7.

valve will be closed. In this case also a stop-cock S will be necessary to let out the air while the pipes are filling with steam.

(849.) *Warming by the circulation of hot water.*—This is a very ingenious process; it consists in having a boiler resembling the boiler of a steam-engine with two pipes, one inserted in the bottom of the vessel, and the other from a point near the top. These pipes, after passing in all required directions through the building, are united in one, and the whole filled with water; the heat of the fire being now applied, the cold water at the bottom being heated will ascend to the upper part of the boiler, and hence continue to ascend in the rising pipe, but communicating its heat to the air as it proceeds it will pass down the descending pipe, where it re-enters the bottom of the boiler to be again heated, when it ascends as before, and thus a continual circulation is kept up and heat distributed to almost any extent. At the Lunatic Asylum for the County of Middlesex, the ingenious Architect, Mr. Sibley, under whose direction that building was erected, has heated the whole establishment by this means from four boilers, each of which gives circulation through half a mile of pipe.

Commonly the heat thus communicated is by radiation from the pipes containing the water in circulation; but Mr. Price, of Bristol, has lately taken out a patent by which the air is first heated by its contiguity with the hot water pipes and cylinders, and is afterwards distributed through the building. An account of this patent is given in the 56th volume of the *Repertory of Arts*. The improvement proposed to be effected consists in a certain arrangement and combination of pipes and vessels connected with the upper part of the ascending pipes from the boiler, which ascending pipes contain the column of heated water, in order to receive the increase which takes place in the volume of water contained in the apparatus as it becomes heated, and also in making the cylindrical pipes to pass one within the other, agreeably to the following description given in the specification. Fig. 4, plate liv., is an elevation of the apparatus, figs. 5, 6, 7 are horizontal sections of what the patentee calls his water-stove, being a series of vessels one within the other, by which the heat is communicated from the hot water to the air; fig. 5 is a vertical section of the same vessel, which will be understood from the following description, the letters of reference being the same in all the figures. A represents the boiler, which is of the kind commonly used in steam-engines, the only difference is in the quantity of water, it being in this case quite filled; the furnace is also nearly the same but need not be so large, and the fuel is applied exactly in the same way. B is an ascending pipe joined to the upper part of the boiler to convey the hot water to the cylindrical vessel C, and D E F G H I, which are peculiar to this patent, form what is called the safety reservoir. The vessel C is of such dimensions as will facilitate the union of these pipes with it, while it serves for the purposes of the reservoir above mentioned, and may contain any quantity of water beyond what is absolutely necessary for the performance of the apparatus, thereby allowing hot water to be drawn off for any useful purpose without interrupting the heating operation. D is a pipe joined to the top of the vessel C, and to the bottom of the vessel E, in order to convey any increased and superfluous quantity of water from C to E. The pipe D is curved down

and up again to form an inverted siphon, which prevents the circulation of the water which might otherwise take place between C and E. E is in the form of a frustum of a cone, open at top, and the pipe D joins to it at the bottom. It receives the water that may proceed from C in consequence of expansion, as above stated, and should be about $\frac{1}{20}$ in bulk of all the water contained in the other part of the apparatus, this being the amount of expansion in water between the temperatures of 52° and 212°. The object of the conical form of this vessel is, that the extent of surface it exposes to the atmosphere may be diminished and the evaporation proportionally lessened as the water rises within it. F is a cylindrical vessel within which the former is placed to receive such water as may overflow. The waste of water from the apparatus, by evaporation or otherwise, may be supplied by other water introduced into this vessel F. G is a pipe descending from F to C, with a stop-cock in it at H, to let down the water from F to C. I is a short pipe joined to the lower part of the loop in the pipe D, and to the pipe G, where it joins to the top of the vessel C, and has a stop-cock at K. When this is opened it allows the loop of D to empty itself of water, which might otherwise obstruct the escape of the air from the apparatus when it is to be filled for working. L is a pipe from the bottom of the vessel C to the bottom of the stove M. N is a pipe descending from the bottom of the stove M to the bottom of the boiler A, and serves to conduct the water from M to A to be reheated. The vessel C should never be entirely empty, and to ascertain the height of the water within it a small vessel s is joined at the lowest part by the pipe r and cock t, so that when the cock t is opened, the cocks H or K being also open to establish a free communication with the atmosphere, the water will rise within the vessel s to the same height it stands within at C. The vessel s is open at top, and is on a higher level than the top of C, and if made of glass the height may be immediately seen.

It remains to describe the stove M, which is formed of concentric cylinders placed one within the other, leaving narrow spaces between them, which are united in pairs at top and bottom, so that the space left between each pair will serve as a vessel to contain water, as represented by the dark parts in fig. 5 and 7. The spaces ff, between the several cylinders, c, d, e, are left vacant for the passage of the air which is to be warmed by its passing through the stove. The bottom of the stove is raised up from the floor of the apartment in which it is placed in order to admit the external air to pass freely, and which thereby gets heated in its passage. The top of the stove is a dome a, covering all the cylindrical vessels of which the stove is composed, and receiving all the air which rises through the open spaces; at the top of the dome is a turning register, of the same kind as is usually applied in other air-stoves, whereby the quantity of hot air admitted is regulated in the usual way. h is a small tube joined to the highest part of the top branch xx, which connects the three vessels c, d, e; this tube passes up through the centre of the turning knob of the register, at the top of the dome a, and has a small cock m at the top, which is opened to allow the air to escape from the open spaces, when the tubes are first filled with water, but when they are full this cock is shut.

To fill the apparatus for action all the stop-cocks, H, K, t, and m, must be opened, then, water being intro-

Mechanical
Processes.Method of
filling the
apparatus.

Manufactures.

duced into the vessel F, it will flow through the pipe G and cock H into the vessel C, and thence, by the pipes B, L, N, into the boiler A, and the stove M, till every part is completely filled. When the water begins to issue at *m* that cock must be shut; and when the height of the water in the glass tube *s* indicates that the vessel C is full all the other cocks must be likewise closed. It may be observed, however, that although we here suppose the apparatus to be filled from the vessel *d*, this is by no means essential; it may be introduced either by a pump or pipe into any part of the apparatus, even into the boiler A, the only condition being that every part be completely filled up to the level of the vessel C. The fire is then lighted beneath the boiler A, and as the water within it becomes heated, and consequently becomes specifically lighter than the water in the other parts which have not been heated, the circulation will begin, the colder and heavier water in the descending pipe overbalancing the hotter and lighter water in the ascending pipe, and therefore the cold water will force its way into the lower part of the boiler, and displace and force from it a corresponding quantity of hot water up the ascending pipe B, into the vessel C; it is obvious, also, that a corresponding quantity of water will run down the descending pipe L, and pass through the stove M, where it will communicate its heat as already described. By this means the water, being cooled and consequently heavier, will descend through the pipe N into the bottom of the boiler, and thus the circulation will be continued as long as the fire is kept up. It is recommended that the ascending pipe and vessel C be covered with wrappers of non-conducting substances, to avoid the loss of heat by radiation and contact with the air, that the ascending column of water may be kept hot while that in the descending pipe is cool.

Warming by hot air.—The method of warming by hot air is considered to be in some cases more economical, but not so generally applicable as the methods above described. When it is practised, a stove or furnace is heated, and the air from without the building is made to pass under the same and enter a space which surrounds the furnace; by this means it is heated in its passage, and, at some point or at various points above the furnace, it is thrown into the room or rooms intended to be warmed, frequently very near the upper ceiling. The stratum of hot air thus found in the upper parts of the building communicates its heat to the next lower stratum till the whole is of proper temperature, and, when the house or manufactory thus heated consists of several floors, openings are made between the upper and lower rooms, the latter deriving their heat from the hot air descending from above. In general, however, this method of warming requires more care in keeping the large doors and openings of the buildings closed than is consistent with a manufactory; but it has been applied with great advantage to theatres, churches, and hospitals. It is attended with great convenience in ventilating in hot weather, for then the same apertures, which form the passage for the air made hot by passing the stove in the Winter, serve to admit the external cold air, whereby a more equable temperature is kept up throughout the year than is attainable by the other methods above described, unless supplied with other means of ventilation.

Public Sewers.

(850.) It may perhaps be questionable whether the
VOL. VII.

Public
sewers.

consideration of sewers is appropriately introduced into this Treatise, but when we consider the immensity of the work, the many miles of open and covered sewers which are employed to drain the vast Metropolis of England, a sort of city beneath a city, and their importance in contributing towards the cleanliness and health of a million and a half of human beings, we think some notice of them is required while we are treating of Works of public and domestic convenience.

It appears that the first Acts of Parliament relating to public sewers were passed in the reign of Henry VIII., and are still in force, although wholly inconsistent with the present state of the Metropolis, at the same time that they interfere with the rates, &c., relating to all the sewers which have been since, or that shall be in future, added. These circumstances have led to various complaints, and, in consequence of petitions presented to Parliament, a Committee was appointed by the House to examine into and report upon the present state of the sewers, and the laws and commissions connected with them, from which Report and examinations, which fill a thick folio volume, the following particulars have been extracted.

“The Metropolis, and the adjacent districts within a circle of 10 miles of the Post Office, are divided into seven Trusts or Boards of Commissions, for the purpose of maintaining the several sewers, water-courses, &c., within their respective districts, each having a separate and independent jurisdiction of its own. Five of these Commissions are administered under local Acts, but two of them take as their guide the old law of sewers, dated as far back as 23d Henry VIII.; which must obviously be altogether inadequate to the complicated wants of the present time. Equally inconsistent with modern notions is the want of publicity and responsibility which characterizes the system established by the old statute. These defects, coupled with the want of uniformity in the administration of the law, and the want of uniformity in the operation of the Commissioners of the different Boards acting independently of each other, call loudly for a remedy, for there can be no question that, however well the system as a whole may operate towards the main object of drainage, it will admit of great improvement, and the charges are certainly very unequally and disproportionally levied. It appears from the examination that a person having property in Finsbury and in Westminster, or in the City and Tower Hamlets, will find himself under the operation of different and contrary rules, whereby he may be led from a knowledge of the regulations of one district to violate those of the other. This part of the sewerage of the Holborn and Finsbury district is conducted through the City into the Thames; and the sewers of the former districts having been greatly improved and enlarged, the quantity of water carried towards the river became so great as to render the sewers of the City inadequate to carry off their contents; which, in addition to the waters from the high lands, were at one time absolutely forced back into the houses from the quantity which occupied the main sewer, and thus after every fall of rain the houses in the vicinity of the City were regularly inundated. This has now been remedied by the Corporation at a great expense and with excessive labour; it proves, however, that combination and uniformity of action are highly requisite to the well-conducting of such a complicated system; and if no speculations have been carried on it is to be attributed to the honourable

Mechanical
Processes.Division of
the metro-
politan
trusts.

Manufactures.

characters of the Commissioners, for the irresponsibility under which each acts furnishes great facilities for such transactions. The Committee in their Report express their satisfaction, that whatever may be the defect of the existing laws, they appear to have been administered with good faith and integrity on the part of the Commissioners."

Annual expenditure and receipt of the Westminster Trust.

The great extent and expenses attendant on these works may be seen from the following statement of the receipt and expenditure of the Westminster and City of London Divisions; it will be seen also how much beyond these is due to individual exertion.

The receipt and expenditure for the last ten years are exhibited in the following Table:—

Year.	Receipt.	Expenditure.
1824 . .	£29,981 16 11	£24,168 1 1
1825 . .	28,837 10 10	24,360 4 1
1826 . .	22,740 19 6	29,410 10 0
1827 . .	28,375 17 11	23,505 17 10
1828 . .	19,209 2 6	27,340 15 3
1829 . .	39,424 1 10	33,998 13 9
1830 . .	28,009 17 9	30,427 8 11
1831 . .	35,394 19 7	23,643 0 11
1832 . .	11,274 12 3	19,724 12 10
1833 . .	37,546 3 2	33,410 3 7
	£280,795 2 3	
Balance carried to the account of 1833 .	10,805 14 0	
	£280,795 2 3	

This large receipt and expenditure has reference to the following parishes, either wholly or in part under the jurisdiction of the Commissioners:—

St. Clement Danes	Wilsden (part)
St. Mary-le-Strand	St. Mary-le-bone
St. Paul, Covent Garden	St. Mary, Paddington
St. John Baptist, Savoy	St. George, Hanover-square
St. Martin-in-the-Fields	St. James, Westminster
St. Ann, Westminster	St. Margaret, ditto
St. Giles-in-the-Fields (part)	St. John the Evangelist, ditto
St. George, Bloomsbury (part)	St. Luke, Chelsea
St. Pancras (part)	St. Mary Abbot's, Kensington
St. John, Hampstead (part)	All Saints, Fulham (part).

There are other parishes named in the Commission, but not included in the local Act under which the Board administer. From a Return, given in evidence by Mr. William Fowler, it appears that the quantity of feet of open and covered sewers built at the cost of the Commission since 1807 is 9578, while, during the same period, the Public, at their private cost, and without any assistance from the sewers' rate, built 91,708 feet.

City of London Trust.

The Commissioners of the City and liberties of London division have within their jurisdiction about 17,600 houses, the rental of which, assessed to the sewer-rate, is £792,904. This comprehends, either wholly or in part, 113 parishes, of which the population is estimated at 122,316. The number of Commissioners is 107; seven constitute a quorum; and the average number who attend the Meetings is from twenty-five to thirty. The salaries of the officers only amount to £570 per annum; and, since the year 1756, about 114 new sewers have been built, wholly or in part. Very great improvements have taken place of late years in the management of this Trust; and the sewers are, generally speaking, in an unobjectionable state. Complaints have been made by several of the inhabitants, who have large and valuable properties in the most crowded parts of the City, of the want of drainage in their neighbourhoods—a deficiency which not only produces serious inconvenience, but has

been prejudicial to health. But there are obstacles of considerable magnitude in the way of the necessary improvements. To construct sewers of sufficient depth to drain the properties in question would endanger several buildings,—one or two of them ecclesiastical structures,—and produce considerable risk of loss and damage; and the Commissioners have hitherto, in consequence of their defective powers and misunderstanding with the individuals who complain, refrained from interfering.

The amount received and expended by the City of London division for the last ten years is as follows:—

Year.	Received.	Balance in hand, after defraying Expenses.
1824 . . .	£5,643 0 0	
1825 . . .	7,500 19 10	
1826 . . .	9,281 11 2	£77 13 10½
1827 . . .	12,430 7 5	701 18 5
1828 . . .	13,006 14 3	1199 13 3
1829 . . .	13,307 14 1	2787 18 7
1830 . . .	14,983 7 9	2822 13 7
1831 . . .	10,068 10 6	
1832 . . .	12,041 5 1	
1833 . . .	17,718 9 4	4379 1 11

The five other Trusts delivered in similar statements.

In the course of inquiry by the Committee several scientific men were examined, in order to ascertain what might be done towards removing nuisances proceeding from the sewage, and affecting the health of the Metropolis. Mr. Fuller, seconded by several medical men of eminence, proposed a plan for purifying the air, by erecting furnaces communicating at intervals with the main sewers; and also suggested the closing of the gully-holes, as they are termed, with traps, so as to prevent the escape of noxious effluvia; but as the expense of erecting these furnaces would be considerable, and as no successful experiment had been made which seemed to warrant the risk of the expense, the Committee decline pronouncing an opinion on the plan, especially as Dr. Faraday, though he approved of it as one likely to succeed, was cautious and guarded in expressing his opinion. The minor improvement of traps for diminishing the admission of foul air from the gully-holes has already attracted the attention of the Commissioners in several of the Trusts, and appears to have been applied with success.

The changes which are suggested by the Committee in the law of sewers are inconsiderable. They see so many objections to a Central Board superseding wholly or in part the Local Trusts—a change which they think would be unpalatable to the inhabitants of the respective districts—that they cannot recommend it without further consideration, and the intermediate trial of smaller improvements. They therefore recommend that, as the composition of the Trusts has given much and general dissatisfaction, (because, although consisting of respectable individuals, a great majority of them have neither the time nor the inclination to attend the Courts,) whenever a Commissioner has absented himself from a majority of the Meetings held for his district within the year, he shall be considered as having voluntarily resigned. It is also suggested that the number of Commissioners should be fixed; and that vacancies should be filled up, in the City of London, by the Common Council, as at present, and in the other Trusts by the vestries of the parishes in the respective districts, by rotation, and in proportion to their relative population

Mechanical Processes.

Recommendation of the Committee.

Manufac-
tures.

and rental. And in addition to this improvement (which would, of course, give the rate-payers a control over the Boards, and tend to destroy the close corporate system pursued) it is recommended that the interpretation of the law in the different Trusts should be uniform, instead of being, as at present, confused and contradictory; that the Courts should meet at fixed times, and be thrown open to the Public; and that the accounts should be subject to general inspection, publicly audited, and submitted annually to Parliament, copies being furnished to all rate-payers, on demand, at a reasonable price. They suggest that works of all kinds should be performed by public contract, with due notice given, but with the understanding that they are to be subjected to the approbation of the Commissioners; there being no public Works in which the inspection of responsible officers is so essential as in those connected with sewers, where defects, concealed easily, if not at once detected, are sure to be brought to light by entailing upon the district subsequently a load of vexation and expense.

The practicability of varying the amount of the rates according to the extent of the advantages enjoyed is attended with considerable difficulties. The principle on which a uniform rate was originally established has been already explained; and as long as the sewage was confined to the surface-drainage it was perfectly just. It certainly is now an unreasonable thing to impose precisely the same amount of rate on streets and houses which have no private underground drains, because there are no sewers within reach into which to conduct them, as upon other streets and houses amply provided with the accommodation of public and private drainage. But how to apportion the expense has been left undecided by the Committee; as has also been the other important point, of how best to secure combination and co-operation among the different Boards.

There is also a great difficulty in fixing the limits of indirect advantage where there is no underground communication with the sewers. For instance, in the Holborn and Finsbury Trust, the inhabitants of the high lands about Hampstead and Highgate are exempted from the payment of sewers' rates, although they are, unquestionably, benefited indirectly by the sewage of the lower districts between them and the river, which are forced to provide a passage for their superabundant waters. But a Court of law has decided that they are not liable, and no rate has been levied by the Commissioners for many years, beyond a certain line.

The sewers' rate is regarded as a landlord's rate, but is paid, in the first instance, by the occupying tenant. It would be expedient, where there is not a special agreement to the contrary, that a receipt given by the Commissioners to the tenant should be in all cases a legal set-off against the rent; while houses untenanted for any length of time, and consequently not contributing to the wear and tear of the sewers, should be allowed a temporary exemption from the rate. This improvement would be a great relief to the inhabitants, as by the existing law the houses are liable for the rate, without regard being had to the recent entrance of the occupants, or the length of time a particular house has been unoccupied.

Whatever doubts exist as to the jurisdiction of the Commissioners should be completely removed. Power should be given them, in all cases, to cover in, enlarge, widen, or otherwise improve open sewers; to compel builders to provide new districts with adequate com-

munications with the main lines of sewers; to rate old property for the construction of new sewers; and to oblige the owners of all houses thus rated to form communications with the sewers when built.

It was estimated by the late Mr. Rennie, prior to the general Macadamizing of the streets, which has much increased the amount of muddy heavy matter, that the daily discharge of the several sewers entering the Thames, within the sewer districts, amounted to 1500 tons per day; with the subsequent increase of population, and the alteration in the paving above alluded to, the present discharge of mud cannot be less than 2000 tons daily, which, notwithstanding the immense quantity of water by which it is accompanied, would appear (did not experience show the contrary) to threaten serious consequences to the navigation of the river.

(851.) With regard to the construction of, or the mechanism employed in, the operation of the sewers, there is little that calls for particular illustration; they are generally constructed of brick in regular cylinders of different diameters, from 3 to 5 feet or more, and are formed where practicable by opening the ground above them, and where necessary by a gallery, as in mining; they are laid at a depth of from 16 to 20 feet below the surface, and therefore descend gradually towards the river, which they enter a little above low water. In some cases, however, particularly on the South side of the Thames, where the sewer can have but little inclination, and is for a considerable distance even below high-water mark, it is necessary to have sluices carefully formed near the mouth to regulate the discharge of the sewer, and to prevent the tide water from ascending it, which would not only produce great mischief by flooding certain parts, but would be liable to blow up the sewer itself. To prevent this the sewer at the place of the sluice is constructed in strong masonry, and two shafts are formed under the sluice-house, one leading to the penstock, which regulates the discharge of the sewer, and the other to the flap which is used to prevent the tide water entering, and which is therefore shut at a proper time of the tide. The latter is a heavy strong circular plane, formed of iron-bound timber, exceeding the interior diameter of the stone sewer, and suspended on heavy hinges above, so that by its own weight it would hang down and close the sewer against the rising tide, but it would also, if left thus, impede the discharge of the sewer at low water; a strong chain is therefore fixed at its lower part, which is made to pass over a guide-pully a few feet in front and a little above the level of the hinges; the chain passes thence to a barrel and winch in the sluice-house, and by means of which it is opened or closed by the sluice-keeper at the proper times of the tide.

The penstock, which is a few feet behind the flap, is also worked by the sluice-keeper in the sluice-house. This is commonly of iron, and with its guide-frame is of very considerable weight, so that, in order to enable one man to work it, great mechanical advantage is obliged to be given. In some cases the winch is made to turn a bevelled wheel whose axle is horizontal, and this to turn another such wheel whose axle is vertical, to which a strong vertical screw is fixed; and this screw working in a nut in the penstock frame rises or depresses is according to the necessity of the case. The shafts to which we have alluded are left open, and furnished with proper ladders, in order to descend and repair or rectify any part of these underground Works when required.

Mechanical
Processes.

Construc-
tion of the
sewers and
sluices.

Manufac-
tures.Water
Works.

Water Works.

(852.) This is a term usually applied to those hydraulic Works by which large towns and cities are supplied with water for domestic uses from some distant source; and to the extensive adoption of such Works we may probably greatly attribute the general healthy state of the immense number of human beings so closely congregated as they are found to be in the Metropolis, and in many other towns in this Kingdom. The Ancients were very deficient in this Art; they are said to have been unacquainted even with the important fact that water in a continuous pipe will always attain to the same height at its two extremes, if not impeded by confined air or some other impediment; and that they, therefore, only conducted their water in pipes down hill, but never carried it up again. This, however, has been questioned; that they did not conduct their water to any extent up hill is admitted, but not from being unacquainted with the principle, but for want of proper materials for the construction of their pipes. The Moderns, however, carry their water along hill and dale to any distance from the original source, distributing it, at the same time, in any lateral direction at pleasure, while the Romans and other ancient nations, either from a want of theoretical knowledge or practical means, could only receive their supply of water from some source higher than the part to which it was directed, and, therefore, if any valley interposed between the two places, very extensive Works became necessary to furnish a passage for the water. These were called aqueducts, and several splendid remains of such Works are still to be seen in many places both in Europe and Asia.

Ancient
and modern
aqueducts.

A very lofty and extensive Work of this kind is still existing in the environs of Constantinople, and remains of others are to be found in Italy and other Countries. The Moderns have also their aqueducts, but they are generally subterraneous, and of much less magnitude than those of the Ancients. Belidor states, in his *Architecture Hydraulique*, that one of the finest subterraneous aqueducts in France is that of Arcueil, three miles from Paris, constructed in 1624, which conducts water from many collecting channels into one large channel of stone. This aqueduct is 14,920 yards in length, and is constructed of freestone; it extends from the valley of Arcueil to an elevated water cistern or *château d'eau* which is at the port of St. Jaques. The channel has an inclination of 6 inches in 400 yards, or of 1 yard in 2400. On each side of the water-course is raised a foot-path 19 inches wide, upon which a person can walk as far as the village of Arcueil. The height of the passage from the bottom of the water trough to the under side of the arch is $6\frac{1}{2}$ feet, except in some places, where it has been necessary to keep it lower in consequence of the high roads passing above it.

Many other subterraneous Works of this kind are found in different parts of France, as also some of modern construction, which are elevated in traversing the valleys they meet with in their course, the most remarkable of which is that erected in the time of Louis XIVth, to conduct water to Versailles and Marly. One of these is the aqueduct of Maintenon. It consists of three courses of arches raised one above another, to support the water-course, which is a channel of stone, and on each side of it a narrow path with a parapet which renders it safe to walk along the side of the aqueduct when it requires cleansing or repair. There is

a description of this Work in the *Philosophical Transactions* for 1726 and for 1728, while it was in progress, and of which abstracts are given in vol. iii. of the Abridgment by Dr. Hutton, pages 187 and 231. From these it appears that this aqueduct is 2560 fathoms in length, and consists of 242 arches; the span of each $6\frac{1}{2}$ fathoms, and the thickness of each pillar, to sustain the arches, 4 fathoms; on the side of the valley next to Maintenon there are 33 single arches, afterwards 71 double ones, that is, having one arch upon the other; then 46 treble ones; at this part the water-course is generally 216 feet 6 inches high from the ground up to the floor of the water channel; afterwards there are 72 double arches, then 20 single ones, which last reach to a mound of earth, which is raised 50 feet high above the ground for a great distance.

Mechanical
Processes.

The general height from the ground up to the second arcade or row of arches is 16 fathoms; from the second row to the third or upper arcade 14 fathoms; in the upper arcade the arches are double the number of those they stand upon; above this it is 6 fathoms 6 inches more to the floor of the channel, which is, at least, 7 feet high besides the parapet. The pillars at the ground are 8 fathoms thick, but, with the slopes and shortenings which are made in every story, the top, where the channel runs, is reduced to 20 feet broad. There is likewise at each pillar a buttress projecting 1 fathom and 2 fathoms wide to strengthen the pillars.

There is another great aqueduct raised on arches in the Plaine de Bue, which conducts water to Versailles from the Plaine de Scale. This is built with 2 ranks of arches, and the lower ones are so much wider than the upper, as to afford room for a carriage-way across the valley about half as high up as the water-course. Drawings of these great Works are given by Belidor. The aqueducts of Great Britain are of a different character to those of either the Roman or the French above spoken of, except, indeed, we consider the New River in that light, which in its object is nearly of the same kind, viz. the supply of water for domestic uses; but this differs much in its general character from the above, while our other aqueducts have for their object, not the supply of water, but to furnish a means of water transit for our minerals and manufactures; and of these the most remarkable in this Country, perhaps in the World, are those of Pontcysylte and Chirk in North Wales, constructed by the late eminent civil engineer, Mr. Thomas Telford.

In this Section we shall confine our illustrations to those Works only of which the object is the supply of water for the general uses to towns and cities, and which in their main principle involve no very intricate mechanical process, although the theory of such Works is by no means obvious, and has, accordingly, engaged the attention of many of our most eminent civil engineers. To determine the quantity of water that will be delivered from a given aperture under a given head or pressure, when that aperture and head are contiguous to each other, is a direct question of computation, resting on the well-known laws of gravity; but, if the aperture of discharge be at any considerable distance from the head, a new question, and one resting immediately on experiment, arises, viz. the amount of friction and resistance of the water in its passage against the sides and bottom, if the canal be an open one, or against the inside of the bore of the pipe if an enclosed one. Moreover, in the latter case, the close pipe may ascend and descend in

Modern
Water
Works.

Manufactures.

its course, and this will again considerably affect the amount of delivery. It is obvious, therefore, that the theory of Water Works involves many considerations which must rest, in a great measure, on practical experience, and this has led several eminent engineers and mathematicians to prosecute long and interesting series of experiments on the discharge of fluids under all variety of circumstances. The greater number of these have, however, been recorded in our elementary Treatises on Hydraulics and Hydrodynamics, so that it only remains for us here to give a concise sketch of the history of Water Works in this Country, the amount of water thus supplied to the people, and a general indication of the mechanical means by which this supply is so largely and conveniently distributed. Such Works are found in all large populous towns in the Kingdom, but those which supply the Metropolis are by far the largest and of most general interest; and, as the principle of operation is necessarily nearly the same in all, we shall confine ourselves mostly to these.

General description of Water Works.

When a town is so situated that the source from which the water is obtained is above the highest point at which the water is required to be delivered, the Works are, of course, very simple. It is only necessary in such case to form artificially, if it does not naturally exist, a sufficient reservoir rendered water-tight at the bottom and sides by puddling or otherwise, to conduct from this reservoir large water mains into the principal parts of the town, and from these mains to lay on branch pipes to the points where the water is to be delivered. In such a case as this where there is no lack of a sufficient supply, the mains may be kept constantly charged, and a cock at the point of delivery, to shut off the discharge when the water is not wanted, is all the Works consist of. But when there is not such an abundant supply, then it is necessary to have means to shut off the water from one part of the town while it is sent to another part, and as, in this case, water cannot at all times be obtained from the delivery cock, a cistern is generally used by the inhabitants to catch such a quantity of water, while it is laid on, as is sufficient to supply their wants during the time it is diverted to another direction. And, to prevent loss from the negligence of the parties supplied allowing their cisterns to overflow and the water to run to waste, these cisterns are, frequently, each supplied with a ball-cock. The ball floating on the water and being thereby lifted with the water surface, and being, at the same time, connected with the handle of the cock, it gradually closes the aperture as it rises, and at a proper height shuts it entirely; but, as the water is drawn from the cistern, the ball again sinks by its own weight and the aperture is re-opened.

From a low source.

These are nearly all the means that are required in cases where the supply is higher than the point of delivery; but when the supply is below, as in the case of a town being supplied from a river running through it or in its vicinity, then additional Works become necessary to raise the water from its lower level to some elevated reservoir, formed on high ground in the neighbourhood, or on the top of some building, thence called a *water-house*, having a large cistern on its top, whence a sufficient pressure may be obtained to direct the water to its several points of delivery. In the latter case, as the reservoir is necessarily limited in dimensions, it must be constantly supplied as the water is drawn off, which, consequently, requires more management and attention than in the former.

Sometimes, also, a certain number of houses or points of delivery are above the level of the highest reservoir; in this case, if the aperture leading to the reservoir were closed and the water forced by the engine, it would, of course, ascend to the points required, but if any excess of pressure were exerted there would be great danger of bursting some of the pipes. To prevent this, a very ingenious contrivance is had recourse to; this consists in a standing pipe, 20, 30, or more feet above the surface of the reservoir, open at top, or returning again in the siphon form. This pipe is connected with the pipes of the upper supply, and it is obvious that, as soon as the pressure exceeds what is due to this head, the water will flow over the top of the pipe into the reservoir below, and thus act as a safety valve to the general system. The means had recourse to for raising the water from the river, well, or low supply, to the reservoir, may be any mechanical agent we have at command. In the smaller Works the forcing pumps may be worked by horses, or, when circumstances admit, by a water wheel placed under a fall of water, or even by the running water of the river itself; but in all larger Machinery the steam engine is our only resource.

Mechanical Processes.

Standing pipe.

Machines for forcing.

Formerly, the pipes which formed the mains were of wood, bored, one end of one pipe being made tapering to be inserted into the larger and thicker end of the other; but, with these means, the pressure that could be employed was very limited. At present by far the greater number of Water Works have iron pipes, some with flanges at each end, which are securely screwed together with lead or other matter interposed between them, to render them water-tight. But more commonly now the iron pipes are inserted one within the other, like the old wood-pipes; for experience taught engineers that a long and continuous pipe, securely screwed together, exceeding about 300 feet in length, would pull itself to pieces by the contraction of the iron from the change of temperature between summer and winter. This change from wood to iron ensures two points, both of great importance, namely, an uninterrupted passage for the water, and great durability.

Wood and iron pipes.

Such is a sufficient illustration of the general principle by which these Works are conducted; we shall now make a few remarks on the progress they have been gradually making in this Country, from the first feeble attempts to the present powerful means and abundant supply of this element, so essential to the comforts, conveniences, and general health of the inhabitants of populous districts.

(853.) *Water Works for the supply of the Metropolis.* —The first attempt at supplying London with water does not seem to have taken place till the time of Elizabeth, in 1581, when a lease was granted by the Lord Mayor and commonalty of the City of London, of the first arch of London bridge, to erect an engine for the purpose of supplying the City with water. The lease was granted for 500 years. In 1583 another lease for 500 years was granted of the second arch for the like purpose. In 1701, a third lease was granted of the fourth arch for 381 years. In 1761 the third arch was granted on lease for 321 years; and, lastly, another lease was granted in 1767 of the fifth arch on the north side and the second arch on the south side, for 315 years. These leases, however, together with the Works, have been wholly cancelled and removed by the construction of the new bridge.

First London Water Works.

What were the nature and power of these Works during

Manufac-
tures.
Description
of the Lon-
don Water
Works as
they were
in 1731.

the period between 1581 and 1731 cannot be now ascertained, but in the *Philosophical Transactions* for 1731 we have a very interesting account of their state at that time, by Mr. Beighton, whose name has already occurred in our History of the steam engine. The Works themselves, as they then existed, were erected at the granting of the third lease, by Mr. Sorocold, and deserve notice, on account of a contrivance had recourse to for raising and falling the water-wheel to accommodate it to the different heights of the water. This was the invention of a Mr. Hadley, who put up the first of the kind at Worcester, for which he obtained a patent.

It appears, from the account above alluded to, that the wheels were placed under the arches of the bridge, and were moved by the common stream of the tide water.

The dimensions are stated to have been as follow: length of the axle of the wheel 19 feet, diameter of axle 3 feet, 8 rings each, 4 arms, 26 floats, length 14 feet, depth 1 foot 6 inches.

The axle rested on two gudgeons, in brasses, or two large levers, which were placed in a horizontal position, and therefore supported the weight of the wheel. The wheel by these levers might be made to rise or fall with the tide in the following manner. The levers were 16 feet long, divided by the fulcrum at 10 feet from one end and 6 feet from the other. At the extremity was a sector or arc of a circle, described from the fulcrum of the lever, and to the bottom of this arch was fixed a long triple chain made on the same principle as a watch chain, but the links were arched to a circle of 1 foot diameter, with notches or teeth to take hold of the leaves of a pinion of cast iron, 10 inches diameter, with eight teeth in it moving on an axis, which was fixed up over the arch, at a considerable height, and the chain went up to the pinion and turned over it. The other loose end of this chain had a large weight hanging at it, to help to counterpoise the great weight of the water-wheel, which prevented the chain from sliding on the pinion. On the same axis as the pinion was fixed a cog-wheel, 6 feet diameter, with 48 cogs. To this was applied a trundle, or pinion, of six rounds or teeth; and upon the same axis was fixed a second cog-wheel, of 51 cogs; lastly, this was turned by a trundle of six rounds, on whose axis was a winch, or windlass. The other lever was provided with a similar chain and wheel-work, and the axis of the last-mentioned trundle was prolonged until the two winches nearly met, so that one man, with the two windlasses, raised or let down the wheel, as there was occasion, to dip always equally into the water.

By means of this Machine, the strength of an ordinary man could raise about 50 ton weight, which much exceeded the weight of the water-wheel.

Near each end of the great axis of the water-wheel a cog-wheel was fixed, 8 feet diameter, and 44 cogs, working into a trundle of $4\frac{1}{2}$ feet in diameter, and 20 rounds, whose axis or spindle was of cast-iron, 4 inches in diameter, lying in brasses, at each end supported by strong timber framing.

And, because the fulcrums of the levers above described were in the line of the axis of the trundle, in what situation soever the water-wheel was raised or let down, the great cog-wheel was always equidistant from the trundle, and worked or geared therewith.

A quadruple crank of cast-iron was attached to the end of the axis of the trundle, the metal being 6 inches

square; each of the necks were distant 1 foot from the centre of motion; the gudgeons of the cranks were sustained in brasses at each end in two headstocks, fastened down by caps. One end of this crank was placed close abutting to the end of the axis of the trundle, which at that end was 6 inches diameter, and had a slit in the end; the crank terminated in the same manner, and an iron wedge was put, one half into the slit in the end of the axis, and the other half into the slit in the end of the crank, by which the axis turned the crank about with it.

Each of the four necks of the crank had an iron spear or rod joined to them, and also jointed at the upper end to its respective lever, within 9 feet of the centre of the lever. These levers were 24 feet long, moving on centres in the middle of their length, and supported by the frame. At each end of each lever was jointed a rod, which descended into the pump barrel, and had the forcers fastened to it. Each end of the four levers worked a quadruple forcing-pump, which consisted of four cast-iron barrels or cylinders, $4\frac{1}{2}$ feet long, 7 inches bore above, and 9 inches below, where the valves were placed; the four barrels were fastened by screwed flanches over four holes in a hollow trunk of cast-iron, which had four valves in it; just over these holes, at the joining on of the bottom of the barrels at one end of the hollow trunk, was a sucking-pipe and grate, going into the water, which supplied all the four pumps alternately, when they sucked or drew up water.

To carry away the water which they forced out, there proceeded from the lower part of each pump-barrel a neck, turning upwards arch-wise, whose upper part is cast with a flanch, to screw up to the under side of another square trunk, which received the necks of all the four barrels; which necks had bores of 7 inches diameter, and over the holes in the trunk, communicating with them, were placed four valves at the jointings or flanches. The square forcing-trunk was cast with four bosses, or protuberances, standing out against the valves, to give room for their opening and shutting; and on the upper side of the trunk were four holes, stopped with plugs, to take out on occasion to cleanse the valves. One end of this trunk was stopped by a large plug, and to the other the iron pipes were joined by flanches, through which the water was forced up 120 feet, or to any height or place required.

Besides this four-barrelled pump, there was such another placed at the other ends of the levers; but to avoid repetition, we have spoken only of one quadruple pump, as the other is just the same; but its rods or forcers being at the opposite ends of the levers, the barrels draw and force alternately.

At the other end of the water-wheel was placed the same sort of work as at the end already described; viz. the great cog-wheel and the trundle fixed upon the spindle or axis, which is united, as before mentioned, with the axis of the quadruple crank.

Also the four rods from these cranks to work the four horizontal levers, each of which had a forcer at both ends, to serve the barrels of a quadruple pump at each end of the levers; so that one single wheel worked sixteen pumps, viz. two quadruple engines at each end of the axis.

The following is Mr. Beighton's calculation of the effect.

"In the first arch next the City was one wheel, with double work of 16 forcers.

Mechanical
Processes.

Manufactures.

Beighton's calculation of the quantity of water raised in 1731.

" In the third arch	First wheel, double work at one end and single at the other .	12
	Second wheel in the middle...	8
	Third wheel	16
		In all 52 forcers.
" One revolution of a wheel made in every forcer		2½ strokes
" So that one turn of the four wheels made		114 strokes
" When the river was in the best state, the wheels went six times round in a minute, and but 4½ at middle water		6
" The number of strokes in a minute . . .		684
" The stroke 2½ feet, in a 7-inch bore, raises		3
		" Per minute 2052 gallons.

" That is, 123,120 gallons = 1954 hogsheads per hour, and at the rate of 46,896 hogsheads in a day, to the height of 120 feet."

This is the utmost quantity they could raise, supposing there were no imperfections or loss at all.

" But it is certain, from the following considerations, that no engine can raise so much as will answer the quantity of water the cylinder contains in the length of the forcer or piston's motion; for, First, the opening and shutting of the valves lose nearly as much of that column as the height they rise and fall. Secondly. No leather can wholly prevent water continually escaping when it is raised to a considerable height; and when the column is short it will not press the leather enough to the cylinder or barrel; but, especially at the beginning or first moving of the piston, there is so little weight on it, that before the leather can expand there is some loss. Thirdly. This loss is more or less, as the pistons are looser or tighter leathered. Fourthly. When the leathers grow too soft they are not capable of sustaining the column to be raised. Fifthly. If they be leathered very tight, so as to lose no water, then a great part of the engine's force is destroyed by the friction."—*Philosophical Transactions*.

By some experiments which Mr. Beighton accurately made on engines, whose parts are large and very well executed, they were found to lose one-fifth, and sometimes one-fourth of the calculated quantity. The imperfections or errors of engines, however, are to be compared together by the calculated quantities or forces; for, as they differ in these, they will proportionally differ in their actual performances.

The power by which the wheels were moved is as follows:

The weight of the column of water on a forcer 7 inches in diameter, and 120 feet high.

$$7 \times 7 = 49 \text{ pounds average in a yard nearly } 40 \text{ yards high}$$

$$\frac{1960 \text{ pounds on one forcer}}{8 \text{ forcers always lifting}}$$

$$\frac{\text{The whole weight on the engine at once}}{15,680 \text{ pounds} = 140 \text{ hundred weight} = 7 \text{ tons weight.}}$$

Then the crank pulls the lever 3 feet from the forcer, and 8.3 feet from the centre.

$$\frac{7 \text{ tons}}{\times 11.3}$$

$$8.3)79.1(9.5 \text{ tons on the crank.}$$

$$\begin{array}{l} \text{Wallower } 2.2) 9.5 \text{ (4.3 on the trundle)} \\ \text{The spur wheel } \dots 4 \end{array}$$

Mechanical Processes.

$$\frac{\text{The radius of the great wheel } 10)17.2(1.72 \text{ ton}}{20}$$

$$\frac{\text{The force of the floats } 18 \text{ hundred weight, } 40 \text{ pounds}}{34.40 \text{ cwt.}}$$

But, to allow for friction and velocity, may be reckoned 1½ ton.

$$\frac{\text{The ladles or paddles } 14 \text{ feet long, } 18 \text{ inches deep } \dots}{22.4 \text{ square feet}}$$

$$\frac{\text{The fall of water sometimes } 2 \text{ feet}}{44.8}$$

$$\frac{6 \text{ gals. in a cubic foot}}{268.8}$$

$$\frac{10 \text{ pounds in a gallon}}{112)2688(24 \text{ hundredweight.}}$$

The velocity of the water 4 feet in 21" of time; 21" : 4 feet :: 60" : 685 feet per minute.

The quantity expended on the wheel, according to the velocity of the stream, 1433 hogsheads per second.

But at the velocity of the wheel 645 hogsheads per second. The velocity of the wheel to the velocity of the water at 1 to 22".

Mr. Beighton makes the following observations on these Water Works: Beighton's remarks.

" Though they may," he observes, " be justly esteemed as good as any in Europe, yet there are some things which might be altered very much for the better.

1. " If, instead of 16 forcers, they worked only 8, the stroke might be 5 feet in each forcer, which would draw a great deal more water with the same power on the wheel; for then there would be but half the opening and shutting of valves, consequently but half that loss; and a five-foot stroke draws above double the quantity of 2 strokes of 2½ feet each by nearly one-fifth, as the velocity is double, which is the most valuable consideration in an engine where the pipes will sustain such force.

2. " The bores that carry off the water from the forcers are too small, there being nearly always two columns of 7 inches diameter forcing into one pipe of the same diameter.

" Therefore, those pipes of conveyance should be nearly 9 inches in diameter.

" The timber work is all admirably well executed; and the composition and contrivance, both for strength and usefulness, not exceeded by any.

" The cranks of cast iron are better than of wrought iron; by reason they are very stiff, and will not be strained, but sooner break; and then they are cheap, and new ones easily put in.

" The wedge for putting on, or releasing the crank and forcers, is better than the sliding sockets commonly made use of.

" The forcing barrels, trunks, and all their apparatus, are very curiously contrived for putting together, mending, altering, or cleansing, and subject to as little friction as possible in that part.

" The machine for raising and falling the wheels is very good, though but seldom used; for they will go at almost any depth of water, and, as the tide turns, the wheels go the same way with it.

" These machines at London-bridge are far superior to those so much famed at Marly, in France, as the

Manufac-
tures.

Smeaton's
Report of
those
Works in
1763.

latter are very ill contrived in the cranks and some other parts."

Such is Mr. Beighton's account of the state of the London Bridge Water Works in 1731; but, in 1763, when the two middle arches of the Bridge were thrown into one by the removal of the pier, the water-way of the river was so much increased that the water-wheels did not perform the same duty as formerly, the amount being reduced to 2716 hogsheads every twelve hours; and it was in consequence of this reduction that the City granted their lease of the fifth arch, for which Mr. Smeaton planned a larger Machine than any of the others. This was erected in 1767, and is described in vol. ii. of the Reports of this distinguished engineer. The several dimensions were as below:

	ft.	in.
Diameter of water-wheel to the extremity of the floats	32	0
Diameter of ditto in the rings, out and out	27	0
Width of wheel, or length of the floats . .	15	6
Number of floats, 24.		
Width of each	4	6
Diameter of spur wheels in the	14	0
Number of cogs, 80.		
Number in the lantern, 23.		
Diameter of water-wheel gudgeons	0	7
Length of cylindrical part	0	7

Notwithstanding this and other additions, and the aid of a steam engine of the old form, (then commonly called a fire engine,) for forcing the water when the tide was very low, and which existed prior to Smeaton's last Work, yet the supply was not all that could be desired; and Mr. Smeaton, being desired to examine the subject, reported that,

"Having carefully examined and considered the construction of your engine, I am of opinion that as, in the present situation of the pipe for supplying the well, the engine cannot have a sufficient quantity of water at low water, I entirely approve of the proposition for laying a horizontal suction pipe, in order that the engine may take the water immediately out of the Thames."

At present, he observes, the whole water is raised by the fire engine to the top of the (water) tower 120 feet, although it most commonly happens that one-half, two-thirds, or three-fourths of that height would be sufficient; and he, therefore, recommended to unite the main from the fire engine with those of the water machine, by which means the fire engine would be relieved of that unnecessary pressure, and, like the water machine, would only be exposed to the pressure on at any time.

These plans, and other subsequent improvements, were made at times, as repairs became necessary; and, in 1821, when a Parliamentary Inquiry took place relative to the different Water Companies in the Metropolis, it appears that the London Bridge Water Works then supplied 29,516,333 hogsheads per annum, and that the number of houses supplied was 32,071, and the annual rental, £35,358.

These Works, so interesting from their early commencement, and from their peculiar Machinery, we have described at some length, and have carried their history through from their commencement to their final removal, although many other important Works were formed during this long period, which ought, perhaps, to have been introduced into our notice between the in-

tervals of the several improvements we have pointed out in the above Works. We have preferred, however, speaking of each separately.

(854.) *New River*.—This important undertaking dates but little later than the second London-bridge lease, having been commenced in 1608, under the authority of Government, with power to bring a new supply of water to the City from certain streams or springs in Middlesex and Hertfordshire. After these powers were granted, various attempts were made, but all of them were abandoned on account of the difficulty and expense attached to such a vast concern. At length, the City made over to Mr. Middleton and his heirs all the power and rights conferred by Parliament, and he began the business at the date above specified. Two springs, one rising near Ware, and the other at Amwell, in Hertfordshire, were united for the supply of an artificial river, which was conducted to the Metropolis. The expenses of the undertaking, however, were so great that they exhausted the fortune of the projector; who, having in vain applied to the Corporation of London for assistance, at length procured it from the King, (James I.) to whom half the share of the concern was made over in consideration of his taking an equal share in the expense.

On September 29, 1613, the water was let into the New River Head at Islington, but the projector was ruined by the expense; and it was long afterwards before the scheme was rendered useful and beneficial to the Public.

The New River is, as above stated, formed by the collected waters of springs which rise in Hertfordshire, about 20 miles from London. These are collected into a large open basin of considerable depth, near which a stone is placed with inscriptions, implying that the stream was opened in 1608, and that from Chadwell Spring the river flows by its windings 40 miles. The original supply of water having been inadequate to the consumption, the mill stream of the river Lea, which runs near it, was resorted to; and, after various disputes and litigations between its proprietors and those of the New River, the mill has at length become the property of the latter Company, who have now an unrestricted use of the water, so that the river Lea may be considered as one of the sources. On a sluice leading from it are flood-gates, with a building, in which a man is placed, whose constant employ is to raise or lower them according to the fulness of the river below; and that he may not err in the quantity supplied, a gauge is fixed across the sluice consisting of a stone of great bulk, under which all the water passes, so that the current is regulated with the greatest exactness. To preserve a proper slope, (3 inches in a mile,) the New River takes such a winding course that the length of the channel is above 39 miles. Passing Ware, Amwell, Hoddesdon, and Cheshunt, it enters Middlesex near Waltham Cross; bending towards Enfield Chase, it turns to the town of Enfield; and, at Bush Hill, was formerly carried across the valley in a wooden aqueduct, or open trough, 660 feet in length, supported by arches; but the improvement in canal-making has suggested a better mode to effect the purpose by means of a mound of earth, over which the river passes in a new channel, which was completed in the year 1785. Hence the river proceeds with devious bends to Hornsey, between which village and Highbury it was formerly conveyed in another wooden aqueduct, now superseded like the

Mechanical
Processes.

New River
Works.

New River
described.

Manufactures.

former by a bank of earth. Still winding, it reaches Stoke Newington, and passes on to the East side of Islington, where it has a subterraneous channel for 200 yards beneath the street. Just before this part is a building, whence several mains or pipes are sent to supply the Eastern side of London. After passing under the road, the New River emerges and coasts the Southern side of Islington, till it reaches its termination at the grand reservoir, called the New River Head. The width of the river near Islington is $14\frac{1}{2}$ feet, the average depth $4\frac{1}{2}$ feet; but the depth decreases on descending towards its source. The number of bridges which cross the river in its whole course is about 200. In various places are sluices to let off the waste water, which, with other Works, excited admiration in the earlier stage of this branch of Mechanics, but are now overlooked in the wonder of canal navigation. The contrivances for distributing the water through various parts of London are also very admirable. From a circular basin, now thrice its original size, which first receives it, the water is conveyed by sluices into several large brick cisterns, whence it passes through large pipes to the several districts, and is conveyed into the houses by leaden pipes. At the New River Head is a building containing two steam engines and a water engine for forcing the water to a higher reservoir near Pentonville, and to another near Tottenham-court-road, for distribution to the Western parts of the town. Near the former reservoir, in a field, is an iron safety pipe, 12 feet high, and 4 feet 8 inches in circumference, with a wooden tub placed on its top, which acts in the double capacity of an air and waste water pipe, and is useful in preventing the bursting of the pipes, which was formerly very frequent from the force of water, or from compressed air.

Shares of the Company.

The property of this great Company was originally divided into seventy-two shares, of which thirty-six were vested in Sir Hugh Middleton, who was obliged to part with them to various persons: these are termed Adventurers' Shares. The other thirty-six were vested in the Crown for the money advanced by King James towards the undertaking. These were alienated by Charles I., and are termed King's Shares; but, as the Crown had no concern in the management, so the holders of these shares are excluded from the direction. The original value of the shares was £100 each, but so discouraging were the first prospects that they fell to a very low price. At present they are worth a hundred times their original value; a rise in property scarcely to be paralleled, and demonstrative of the increase of buildings in the Capital. The management of the Company's affairs is vested by Charter in twenty-nine holders of Adventurers' Shares, who form a Board. The officers are, a governor, deputy governor, a treasurer, and a clerk. Few public Companies surpass this in property and extent. The constant repairs and improvements employ a vast number of men and horses; and the whole system of the distribution of the water is so complicated as to require the utmost skill and attention on the part of the surveyor and other officers.

It appears that the New River Head is $84\frac{1}{2}$ feet above the Thames; and, consequently, a great part of the water supplied requires no Machinery. Some houses, however, are situated above this level, and to supply these a higher reservoir is required. In the first Works the water was forced to this level by a windmill. A horse-mill was afterwards employed prior to 1767; (pro-

VOL. VIII.

bably about 1737;) this was supplanted by a steam engine; and this again was replaced in 1787 by one of Bolton and Watts's. The number of steam engines employed at these Works in 1820 was three, of sixty-three horse power. The following document, however, submitted to the Committee of the House of Commons in 1821, will give a much better view of the extent and importance of this Work than any detached statement we can make; and it will, we are convinced, be very interesting to the curious reader.

Mechanical Processes.

(855.) *Estimate of the Capital engaged in the Works of the New River Company, taken A. D. 1815; also, a further estimate to Christmas A. D. 1820.* Statement of the different Works, and value of the New River Company.

	£.	£.	s.	d.
For the original purchase of the springs of Chadwell and Amwell, the remuneration to the millers upon the river of Lea, the purchase of the land for the formation of the river, the excavation of the ground, the levelling and puddling of banks, timber and brick wharfing at various places on the banks, of 80 miles in length, the embankment of various valleys, and the tunnelling, in two instances at £5 5s. per yard, run on 40 miles in length	...	369,600	0	0
To the erection of 157 brick, timber, and iron bridges, at £100 each	...	15,700	0	0
Protecting fences where the river runs parallel with the roads, and cross fences where the river is at right angles with the division of lands	...	15,000	0	0
To making 58 proper culverts for taking away the rain water, at £140 each	...	8,120	0	0
To making three flashes	...	7,500	0	0
To making five waste gates	...	3,500	0	0
To making two stop gates, with walksmen's houses thereto	...	9,000	0	0
The value paid by Act of Parliament, in 1734, for an additional portion of the river Lea	...	3,250	0	0
To the purchase of Ware mills, as necessary for the government of the water	...	9,000	0	0
Formation of balance engine	...	7,000	0	0
Erection of marble gauge, and two other stone gauges, and tumbling bays. Erection of stop gate, and cut into New River	...	6,500	0	0
The purchase of 60 acres of land adjoining the river at various places	...	6,000	0	0
The formation of reservoir, for the reception of the water when brought to London. The purchase of land for the original circular pond, excavation, wharfing, stop gate, &c.	...	12,000	0	0
Ditto the outer Head, ditto	...	16,000	0	0
Ditto the High Pond, ditto	...	12,500	0	0
Ditto the pond at Tottenham-court-road, ditto	...	16,000	0	0
Ditto the reservoir in St. John-street ditto. Ditto the West Pond in Hanging-field ditto	...	5,000	0	0
The formation of cisterns for the filtering of water previous to its passing to London. Waterhouse cistern, and dwelling thereon	8,000			
Middle ditto and house	3,000			
Out ditto	2,500			
West ditto	2,000			
Duck ditto	500			
Green Man's ditto with another small cistern adjoining	2,000			
Three high ponds, cisterns, and two houses	1,500			
Carried forward	19,500	523,670	0	0

4 H

Manufactures.	£.	£.	s.	d.
Brought forward...	19,000	523,670	0	0
Two cisterns in Pipe-yard, and house and sewer thereto.....	1,000			
Dalby's cistern and house.....	1,000			
Bullock ditto.....	2,000			
Two West ponds, cisterns, and house ..	750			
Two cisterns at Newington-lane, and one in Hopping-lane.....	750			
To the various sewers from the above eighteen cisterns	1,800			
		26,800	0	0
Machines necessary for the improved mode of supply as now required:				
To the erection of two engine houses, and engine workers' houses, &c.	15,000			
To various tunnels underground, and well for pumps				
To the purchase of two large steam engines and fitting up the same complete ..	9,500			
To a large water wheel fixed in a house of brick, and brick cistern	4,500			
To the formation of a large brick sewer, from the tail of the same to a considerable distance into Clerkenwell ...	2,800			
		31,800	0	0
To the purchase of various iron pipes, and the cost of laying down the same.				
Two mains for connecting the High Pond with the steam engine, 16 and 17 inches.				
Another, connecting the West Pond with the out Head, 24 inches.				
Ditto the steam engine with Tottenham-court-road reservoir, and into town, 20, 18, 16, 15, and 14 inches.				
Ditto the steam engine with Tottenham-court-road, 18, 16, 14, and 12 inches.				
Ditto from the New River Head to St. Giles's, 18 inches all the way.				
Ditto to Clerkenwell, 10 inches.				
Ditto from the reservoir in St. John-street-road to Clerkenwell, 14 and 12 inches.				
Ditto to Goswell-street, 22 inches.				
Ditto to Shoreditch church, 19, 18, 17, 16, and 15 inches.				
Ditto from the Bullock cistern to Old-street-road, 12 in. and three others from Bullock cistern a short distance.				
Ditto from the West Pond to Gray's-inn-lane.				
Ditto from Tottenham-court-road reservoir to Oxford-street, 12 inches.				
For other 10, 9, 8, 7, and 6 inch mains in iron, and for service pipes in iron of 5, 4, 3, and 2 inches.				
For cocks of various sizes, as above mentioned.....				
To the cost of 257 miles of wooden mains and services, now in the ground, which has been estimated at £200,000, in iron and wood, at the following prices.....				
3. 141,554 at 4s.				
4. 129,853 at 5s.				
5. 28,966 at 6s.				
6. 41,884 at 8s.				
7. 54,875 at 10s.				
		113,654	19	0
To the cost of the various cocks for the above-mentioned mains and services..		15,000	0	0
Monies expended in the purchase of grants to lay pipes through private property		5,000	0	0
Ditto for the repairs of sewers in laying the above pipes.....		5,000	0	0
Ditto for various sums expended in obtaining the necessary Parliamentary powers.....		109,950	0	0
		£956,640	7	0

(856.) *The Chelsea Water Works* were commenced in 1732, by authority of Parliament, the number of original £20 shares having been 2000, but, in 1734, 2000 other £10 shares were issued. This Company draws its supply from the Thames, and has consequently to raise all its water by steam power.

The quantity of water supplied by these Works in 1820 was 7,533,900 hhds.
Number of houses supplied 8,632
Annual water rental £12,586

East London Water Works.—These are the next in importance to the New River Works.

The quantity of water supplied by these Works in 1820 was 29,516,333 hhds.
Number of houses supplied ... 32,071
Annual rental £35,358

Grand Junction Water Works:
The quantity of water supplied in 1820 13,104,000 hhds.
Number of houses supplied ... 7,180
Annual water rental £20,468

West Middlesex Water Works:
The quantity of water supplied in 1820 11,904,100 hhds.
Number of houses supplied ... 10,350
Annual water rental £25,915

The grand total of all these, including the old London Bridge Water Works, was, therefore, in the above year,

155,381,038 hogsheads of water.
120,000 houses.
£175,890 water rental.

Since the above period, great changes have taken place in the amount supplied from the different Companies, in consequence of the removal of the London Bridge Works, as will be seen as we proceed. We have spoken above only of the Water Works on the North side of the Thames: besides these there are three Companies on the South side, i. e. the Lambeth Company, the South London Company, and the Southwark Company, the amount of which supplies was not stated in the Report of 1820.

(857.) Another inquiry, however, took place in 1828, in consequence of the great complaint made by the inhabitants of those parts of the town which received their supply from the Thames, the water of which, never very pure, is now rendered wholly unfit for any but the most common uses, from the great increase of common sewers, and the refuse of gas and other Works, which are daily discharged into the river. Petitions were accordingly presented to Parliament, and a Committee of the House was appointed in July of that year to inquire into the matter. This Committee, after examining several scientific men, and inquiring into the system pursued by the different Water Companies, made their Report to the House; in which they stated it as their opinion, "That the then present state of the supply to the Metropolis was susceptible of and required great improvement, and that many of the complaints relative to the quality of water were well founded, that the supply ought to be derived from other sources than those then resorted to, and that it should be guarded by such restrictions as would at all times ensure the cleanliness and purity of an article of such prime necessity;" and the Committee further recommended

Mr. Telford's proposed improvements in the London Water Works.

Manufac-
tures.

that Mr. Telford should be instructed to make such surveys as he should think necessary in order to enable him to recommend a practicable and efficacious plan for supplying the whole of the Metropolis with pure and wholesome water. This recommendation, however, was not acted upon by Government authority till March, 1831, and even then not till Sir Francis Burdett stipulated to exonerate the Public from any of the expense attending the operations; a pinching and unprofitable economy, which was afterwards abandoned by the Treasury upon the ground, "that it was the duty of the Government to give effect to the recommendation of the House of Commons."

Nothing, however, has yet been done towards practically remedying the evil, the inhabitants being

still supplied by six out of the eight Water Companies with water drawn from the impure source of the Thames. Another Committee has been formed, and Mr. Telford's Report presented, with a plan for supplying water from two rivers, one on each side the Thames. Before, however, referring more particularly to this proposition, we propose to give again an abstract of some Tables on this Report, relating to the quantity of water supplied daily by the different Companies in 1833 and 1834, which so far exceeds those of 1821 as would make them appear incredible if not given under such undoubted authority, amounting as it does in the aggregate to the extraordinary quantity of about 40,000,000 imperial gallons daily, as will appear from the following statement.

Mechanical
Processes.

(858.) *Extract from the Report of the Committee of the House of Commons appointed to inquire into the State of the Water supplied to the Metropolis, 1834; containing the Returns as officially supplied by the different Water Companies.*

New River.							
Houses and Buildings supplied.	Gross Rental.	Average Rates per House or Building, including large Consumers.	Total Quantity of Water supplied Yearly in Hogsheads.	Average Charge per 1000 Hogsheads computed in Gross Rental.	Average daily Supply per House or Building including Manufactories, &c. &c.	Mean Elevation at which the Water is supplied.	Highest Elevation at which the Water is supplied.
70,145	£. 98,307 Exclusive of rents for lands, &c.	s. d. 26 6 Exclusive of rents for watering streets.	114,650,000	s. d. 17 1½	Gallons. 221	Feet. 84½ Elevation of river head.	Feet. 145 About one-eighth of the whole supplied at this pressure.

Chelsea.									
[Office of Chelsea Water Works, Great Queen-street, Westminster, 16th May, 1834.]									
Average per Share.	Estimated Current Expenditure for the future, exclusive of Reverse Fund.	Houses and Buildings supplied.	Gross Rental.	Average Rates per House or Building, including large Consumers.	Total Quantity of Water supplied yearly.	Average Charge per 1000 Hogsheads, computed on Gross Rental.	Average daily Supply per House or Building, including Manufactories.	Mean Elevation at which the Water is supplied.	Highest Elevation at which the Water is supplied.
£. s. d. 56 10 6	£. 13,481	13,892	£. 22,906	s. d. 33 3	Hogsheads. 15,753,000	s. 29	Gallons. 168	Feet. 85	Feet. 135

An Account of the Average Supply of Water throughout the Year, showing the Maximum and Minimum daily Supply from the Year 1828 to the Year 1833, in Imperial Gallons.				
Years.	Maximum.	Minimum.	Average for the Year.	
1828	2,620,000	1,728,000	2,020,000	During these five years the water has been raised from the river, and filtered previously to being pumped into the district.
1829	2,825,000	1,871,000	2,161,000	
1830	2,400,000	1,846,000	2,138,000	
1831	2,332,000	1,944,000	2,187,000	
1832	2,434,000	1,895,000	2,162,000	
1833	2,992,000	2,016,000	2,337,000	

Manufactures.

Mechanical Processes.

Middlesex.

Total Quantity of Water supplied yearly.	Greatest Quantity delivered per Day in August, 1833.	Charge per 1000 Hhds.	Average of each Supply per Day.	Elevation at which the Water is supplied.		
				Kensington Reservoir.	Barrow Hill Reservoir.	Mean.
5,000,000 tuns. 20,000,000 hhds. 1,080,000,000 gallons. 180,000,000 cubic ft.	Gallons. 3,800,000 or $7\frac{3}{8}$ cubic feet per second.	s. d. 45 6 or about a half-penny per hhd., conveyed an average distance of five miles, and delivered at a mean height of 155 feet.	Gallons. About 185	Feet. 122	Feet. 188	Feet. 155

East London.

Supply of Water for the Year 1833	5,593,896 Imperial gallons per 24 hours.
Ditto Maximum	6,194,700 Ditto
Ditto Minimum	4,874,004 Ditto

Average Rates of House or Building, including large Consumers.	Total Quantity of Water supplied yearly.	Average Charge per 1000 Hogsheads, computed on Gross Rental.	Average daily Supply including Manufactories.	Mean Elevation at which the Water is supplied.	Highest Elevation at which the Water is supplied.
s. d. 22 9	Hogsheads. 37,810,594	s. 28	Gallons. 120 $\frac{1}{2}$	Feet. 60	Feet. 107

South London.

Gross Rental.	Average Rate per House.	Total Quantity of yearly Supply.	Average daily Supply in Houses and Manufactories.	Mean Elevation.	Highest Elevation at which Water is supplied.
Annual Rates about £9000. The amount received for water rates from March, 1833, to March, 1834, £8839 16 10	About 15s.	A few years ago the annual average supply was calculated at about 300,000,000 of gallons of 282 cubic inches, but no accounts have been kept to enable the Company to furnish a Return.	The difficulty of furnishing the information required in the other column applies necessarily to this; the average daily supply is supposed to be about 100 gallons to each tenant, or about 1,200,000 gallons daily.	No basis upon which to form a calculation; no separate account ever having been kept of high and low service.	80 feet.

Lambeth.

Estimated Current Expenditure for the future, exclusive of Reverse Fund.	Houses and Buildings supplied.	Gross Rental.	Average Rates per House or Building, including large Consumers.	Total Quantity of Water supplied yearly.	Average Charge per 1000 Hogsheads, computed on Gross Rental.	Average daily Supply per House or Building, including Manufactories, &c.	Mean Elevation at which the Water is supplied.	Highest Elevation at which the Water is supplied.
£. 6,500 Without allowing for filtration.	16,682	£. 14,808	s. 17	11,998,600	£. s. d. 1 4 8	Gallons. 124	Feet. 55	Feet. 185

Manufactures.

Grand Junction.

Mechanical Processes.

Gross Rental.	Average Rates per House or Building including large Consumers.	Total Quantity of Water supplied yearly.	Average Charge per 1000 Hogsheads computed on Gross Rental.	Average daily supply per House or Building, including Manufactories, &c. &c.	Mean Elevation at which the Water is supplied.	Highest Elevation at which the Water is supplied.
£ s. d. 21,461 1 10 ordinary service. 4,017 8 4 high service. 675 18 10 street watering. 26,154 9 0	s. d. 48 6 For ordinary service.	Hogsheads. 21,702,567	s. d. 24 1 per hogshead.	Gallons. 350 and thirteen gallons per House per day, for street watering.	Feet. 100	Feet. 156 9

Southwark Water Works.

Houses and buildings supplied, 7,100.

Gross rental, £7,850.

Average rate per house, including large consumers, 21s. 3d.

Total quantity of water supplied yearly, 7,000,000 hogsheads of 63 gallons.

Average charge per 1,000 hogsheads, 21s.

Average daily supply per house, including manufactories, &c., 156 gallons.

Cisterns generally 38 feet high, being the mean elevation at which the water is supplied.

The greatest elevation at which the water is supplied 60 feet.

Mr. Telford's Report.

(859.) In the course of his survey Mr. Telford examined the capabilities of the river Colne, which passes at Uxbridge, after having received at Rickmansworth the waters of a considerable stream called the Chesham. He found that, except after heavy rains, the Colne is an insignificant stream quite inadequate to the purposes required, and when swollen by rains that the water was unfit for domestic use on account of its muddiness; but about half way between St. Alban's and Watford the Colne joins the Verulam, a transparent stream which occupies the valley of the former town. At Watford mill, in 1833, being a remarkable dry year, the Verulam river produced 16,200,000 imperial gallons daily, a quantity, he considers, amply sufficient for the required purpose, although new buildings in the North-Western district should be added to a considerable extent, or as numerous as during the last twenty-five years.

About two miles above Watford the valley of the river affords a commodious situation for extensive reservoirs of water, and for allowing it to settle if such should be thought necessary. From this place, the projectors proposed to convey a covered aqueduct to descend with a uniform inclination of 18 inches per mile to Primrose Hill, North of the Regent's Park, terminating there in extensive receiving and distributing reservoirs at the height of 146 feet above the high-water mark of the River Thames. From these reservoirs each of the three Companies for supplying the North-Western district might be supplied separately, and in any proportions that might be determined upon.

To deliver the water into the reservoirs at Primrose Hill as pure as it leaves the Verulam, it is proposed to

convey it through a covered aqueduct, and at such a depth below the surface of the ground as to be secure from the effect of frost and from external injury, preventing also mixture with surface water. To remedy the inconvenience occasioned by cleansing and repairing, Mr. Telford proposes constructing the aqueduct with a double watercourse, separated by a footpath through its whole length; and to provide an adequate supply in the probable event of an increased population, he suggests that the aqueduct should be made sufficiently large to convey the whole quantity of 30 cubic feet per second furnished by the Verulam. The analysis of this water, which has been made by persons of the first Chemical eminence, as well as the adduced testimony of various persons residing in or near Watford, leave no room to object in any way against the purity and excellence of the water which it is thus proposed to bring to the supply of that part of the metropolis. The quantity of water required for the supply of the inhabitants South of the Thames is much less than that required on the North side, 10 cubic feet per second being stated as a quantity adequate to the purpose.

Mr. Telford proposes to supply this quantity from the river Wandle, at a sufficient elevation, found on the Croydon branch, at the East of Beddington Park, 90 feet above high water in the river Thames. From this place an aqueduct, similar in its construction to that above described, may be carried in nearly a direct line to Clapham Common, and there terminate in the requisite number of reservoirs at a height of 82 feet above the highest level of the Thames, and which, with the single exception of Brixton Hill, exceeds the height of delivery effected by any one of the three present Companies supplying this district.

The main branch of the Wandle takes its rise in a singularly copious spring, in the vicinity of Croydon, and after pursuing a Westerly course for about three miles is joined by the Carshalton branch, which likewise derives its origin from several plentiful springs in that neighbourhood. The water of this river possesses at all times an uncommon degree of purity, regaining its transparency after the heaviest rains in the course of a few hours.

The quantity of water flowing down the Carshalton branch of the Wandle in the extraordinary dry season of 1833 was at the rate of 13 cubic feet per second

**Manufac-
tures.**

while the quantity discharged by the Croydon branch was at the rate of 17 per second; there can, therefore, be no doubt of the adequacy of the source whence Mr. Telford has proposed to draw the supply of water necessary for the inhabitants of the Southern part of the metropolis.

It seems unnecessary here to go into any description of the means possessed for the same purpose, as regards the North-Eastern district, by the New River and East London Companies, both because it is not proposed to make any material or immediate alteration in their present arrangements, and because the necessary particulars may be gathered from other sources. There can be no reason for doubting the adequacy of the river Lea for the purpose of supplying, if such a necessity could arise, the whole Northern district of London; since we are told, on the authority of Mr. Telford, that in the month of November, 1833, the quantity of water flowing down that river was found to be 110 cubic feet per second, *after supplying the New River*. Some suggestions are made in the Report, by adopting which the original purity of the water of the Lea would be preserved more completely than at present; but a description of these plans involves merely technical details, which would hardly be interesting to our readers. It may, however, be well to mention, that the water of the Lea is originally of the same quality as that of Verulam, the sources of both being from the great chalk ridge which intersects Hertfordshire.

To effect the objects proposed by Mr. Telford, of conducting the waters of the Verulam and the Wandle for the supply of London, a considerable outlay of money would be required. An estimate of the cost of the various Works is given, showing an amount,

For the North side of	£785,965
And on the South side of . . .	391,875
Together	£1,177,840

a very large sum of money, undoubtedly, and which, being beyond the means possessed by the existing Companies, must in the outset be advanced by Government. This consideration should not, however, be allowed to stand in the way of accomplishing so important and necessary an object as the supply of wholesome water to the metropolis; and especially as means have been pointed out whereby the interest could be paid upon the outlay without adding in any way to the public burthens. The plan for this purpose was proposed by the Directors of the Grand Junction Water Works Company, and was to this effect: that the Government having advanced the sums required to bring the water to the spots whence the Companies could receive it into their respective Works, each of these establishments should pay its proportion of interest, according to the quantities of water respectively used by it, the rates of the Companies being pledged to the Government as security for the payment of the interest. On the other hand, it was proposed that the Companies should be authorized to make such an addition to the rates charged to their customers as would compensate them for this payment, taking into consideration that their constant annual outlay for pumping and filtration would be materially lessened by the adoption of the plans proposed. To this additional charge the Public could not fairly object, the advantage of securing a plentiful supply of pure water being sufficiently great to compensate for the

small additional charge that would be necessary for the purpose. (See Telford's Report.)

**Mechanical
Processes.**

Works relating to the Construction of Wharfs, &c.

(860.) The term Works is generally applied to the various preparatory steps towards the construction of wharfs, basins, canals, locks, &c., and we take advantage of this circumstance to describe in this place some processes or principles of construction which have been introduced into practice since our Articles Canal, Dock, &c., were written in the general alphabetical arrangement of this Work. These relate to the formation of wharfs and dock walls, &c. Hitherto, in forming the front of any wharf against a tide river, it was considered necessary to form what is called a coffer dam, by driving in front of the intended wall a double row of piles, and to throw and work in clay between the two rows, in order to keep out the water from an excavation made behind them, for laying in the foundation of the wall, and while raising it to the intended height; after this has been effected, and when every thing is completed, the piles which had formed the coffer dam are drawn up again, and the river admitted to the wall, the latter being properly defended by timbers placed there for the purpose.

These operations are, of course, attended with great labour and expense, and, with a view to avoid or reduce these, several ingenious engineers and architects have lately turned their attention to means of constructing wharfs and other walls without incurring such vast expense and labour. The plans proposed have been, first, to construct the wall by driving iron piles and to fit iron plates between these, so as to form the proper face; another, which has been proposed as a more substantial mode of proceeding, is to form the whole with iron piling; and a third method is to form the wall of a concrete which sets under water, and sufficiently solidifies to form a substantial wall in every respect resembling actual stone.

We have already, under the Article Pile Engine, referred to the two former of these propositions; the first being the projection and execution of R. Sibley, Esq., architect, Great Ormond-street, and the second by James Walker, Esq., civil engineer. We could not properly in that Article do more than refer to the two cases above mentioned, but we have, by permission of the latter gentleman, been furnished with a full description of a Work of the kind constructed at Blackwall, by Mr. George Bidder, who superintended it while in progress; and to whom we are much indebted for the very accurate drawings which are given on a reduced scale in plate lxxv.

Iron wharf at Blackwall.—The Directors of the East India Docks having resolved upon rendering a portion of the Dock premises facing the river, upwards of 700 feet long, a commodious quay for the accommodation of all descriptions of steam-vessels frequenting the port of London, a question arose as to the best mode of effecting this; viz., whether by jetties, or a continuous line of wharf, composed either of brickwork, iron, or timber.

The objection to the jetties consisted in this; that they must have projected considerably into the river to attain a sufficient depth of water for steamers to lay afloat at all times of tide, thereby interfering with the navigable part of the river by narrowing it.

Moreover, it is not very commodious, as being

Iron wharfs.

Manufactures.

necessarily removed some distance from the offices and sheds situated on the old wharf; while the transit of goods to and from the vessel would be exposed to delays and expenses of serious consequence to the rapid delivery required for much of the cargoes now conveyed by steam.

For these and other reasons the continuous line of wharf was determined on; and it only remained to decide on the material of which the wharf should consist.

A stone or brick quay wall is clearly the most substantial and durable; but, as above mentioned, it being a *sine qua non* that steamers should have the opportunity of coming and leaving at all times of tide, it could not be founded less than 12 or 13 feet under low water, Trinity standard, and to have done this would have required a very substantial coffer dam. The cost and time requisite to complete this, before a brick could be laid, would necessarily be so great that it was thought proper to endeavour to find a sufficient substitute.

The advantage of cheapness afforded by a wooden frontage was thought to be more than counterbalanced by the great current outlay which must shortly have ensued from its decay and great height, exposed to the effects of wind and water.

The Directors were therefore thus induced to try the experiment of constructing in this place an iron wharf.

The City being applied to granted permission to the Dock Company to extend their premises, on an average about 20 feet into the river. The locality of the line of frontage being thus settled, it afforded to Messrs. Walker and Burges the data upon which they adopted the principle of its construction.

For as the depth of water against the wharf, to allow steam-vessels to lay afloat at all periods of tide, could not be less than 11 or 12 feet, and the tide in the river Thames flowing 18 feet on a medium, and occasionally 3 feet higher, as in February of this year, the whole height of the wharf could not be less than 34 feet.

This at once decided the necessity of having an uninterrupted line of sheet piling at bottom, because the principle adopted in other wharfs, of inserting at regular intervals grooved piles and filling up between with plates, could not be applied here, inasmuch as that, before a plate could be fixed, the ground must be cleared away, and this would have infallibly destroyed the old wharf, as the excavation would have left its foundation exposed for a depth of 13 or 14 feet. Moreover, had this objection been surmounted, it would have been found that the expense of fitting these plates under low water, from the usual irregularities of casting, must have been very great.

In consequence, it was found necessary to adopt a practical plan of more general application.

To carry the piles the whole depth of the wharf, *viz.* 34 feet, without allowing for hold of ground, would have caused them to be very unwieldy and difficult to drive, as from greater length the chances of their being cast crooked is considerably increased; they would, in consequence, twist in driving, and if a strain was applied to keep them in their proper lines it would only bend them, and render the evil worse; further, their liability to break would be increased three or four fold. It was in consequence determined by Messrs. Walker and Burges to have a row of piles to a certain height, and the rest to be made up of main top piles and intermediate plates.

It was the opinion of many professional men that iron

piles could not be driven through soil so hard as that known to exist in the bed of the river in the neighbourhood of Blackwall, especially if in the line of wharf any of the well-known Blackwall rock should be encountered, this being a concrete of gravel and the oxide of iron, obtained from the land springs flowing through the gravel beds. This stratum varies from 6 inches to 18 inches in thickness, and though it is easily fractured when unsupported underneath, yet when resting on a solid bed of gravel it is very difficult to penetrate.

Experience, however, has proved that iron piles can be driven through this, as it was met with in several places, requiring, nevertheless, great care in driving. In one place, two of the main piles were broken before the stratum could be penetrated; the sheet piles, from the greater sharpness of their points, and less sectional area, were much more readily driven through it.

The length of the fall of the ram was restricted to four feet, and if the soil in any case was found to be more than ordinarily hard, from the shaking of the pile, or if any strain was requisite to be used to keep a pile to its lines, the blows were further reduced.

The jar of the blows was obviated by a board of elm, three-quarters of an inch thick, interposed between the head of the pile and the monkey; one of these boards, if of good stuff, and the pile-head fair cast, would frequently drive a pile its whole depth, *viz.* 16 feet. The ram weighed 15 cwt. and the piles usually drove in 5 blows one inch; sometimes, however, they required 20 blows for the inch.

In some instances, when the pile-heads broke from defects in the castings, a cast-iron dolly or cap was used, 2 inches thick, to receive the blows of the monkey.

The only difficulty experienced in driving them, to retain them at their proper lines, arose from irregularities in the casting; it often happened that piles came an inch hollow in their face, and sometimes as much rounding; of course it could not be expected that piles, which could not fit previous to their being driven, would be any better after driving; further, from their crookedness, as must be known to all experienced in pile driving, it is almost impossible to drive them as they are pitched, as the blow of the monkey cannot be kept in the centre of the pile; the straight piles kept their direction with great accuracy, unless when they were encountered by soil of unusual hardness, or by wooden piles and stumps in the ground.

Five of the piles only were broken from hard driving; the rest of the casualties were all from manifest defects in the castings, such as air holes, defect of metal in sectional area, imperfect connection of the metal when the different runnings met in the mould by cooling too quickly; it was fortunate that it proved so, for the difficulty in drawing the piles partly driven was very great. Bolts, 2 inches diameter, of the best iron, were frequently broken at close bearings by the strain, and in two instances, after a strain of upwards of 80 tons was tried in vain, the piles were obliged to be made good by splicing the top piece to the lower.

As the wharf curves sharply at each end, a difficulty presented itself from the toes of the piles having to spread more than the head, as they described a longer circumference from the batter of the wharf; this of course had to be overcome by piles of a parallel width, but was not effected without much difficulty.

Nevertheless, from the scale of the application of iron in this instance, *viz.*, 750 feet long, 33 feet high, and

Mechanical Processes.

Manufac-
tures.

from the nature of the soil driven through, the practicability of its application to river walls, &c. is clearly proved.

Yet more care is certainly required from the people in pitching and driving these piles than wooden piles, as no adjustment can be obtained, when any irregularities occur, by altering the form and shape of the pile to suit any particular purpose. The castings were executed principally at the Butley Company's Iron Works, near Newcastle-on-Tyne, and the very few fractures which occurred, after they became aware of the nature of the Work, is very creditable to that establishment. Some of the piles were also supplied from the Horsley Company's Works, Staffordshire.

Pl. lv.
Fig. 1.

Fig. 1 is a section of the wharf, *a b* is the front of the old wharf; *c d* is what is called a needle, driven in every seven feet for the purpose of receiving the ties which secure the iron pile, which is itself tied back by a land tie to a wall on the old timbers, as shown in the section; *e f* is a wooden guide pile, one of which is driven every 14 feet, carrying the wales *g g*, which serve for direction in driving the iron piles, and also for bolting thereto the sheet piling. Fig. 3, *k k*, is a mass of concrete filled in, and forming the back to the iron piling, 22 feet deep, 9 feet broad at bottom, and 5 feet 4 inches at top, by which the back is perpendicular to the horizon.

Fig. 3.

Fig. 2 is a front elevation of the wharf. The main piles are in two lengths, their joining parts being marked *a a*, &c. The section of the upper length is represented in fig. 3, at *l*, and of the bottom length at *m*, and the plan of the point of joining at *n*; the square hole in the bottom pile for receiving the spigot of the upper pile is shown also in the figure, and *h* is a hole through each flanch for receiving a $1\frac{1}{2}$ inch bolt for additional security. The sheet piling is shown at *b b*, &c., but its figure will be better understood by the section, fig. 3, where *r* represents a rib for covering and receiving the abutting end of the next pile; this is, of course, only required at one end, the other *r* being received behind the flanch on the main pile; *d d d*, &c. represent the plates for filling the space between the main piles above the sheet piling, the section and method of securing which is shown by *s s*, fig. 3, one of these flanches being on each plate, and are bolted together through the holes seen in the plan.

The plate in fig. 2 is what is called the mooring plate; this is cast concave to receive a mooring ring, which, by this means, does not project beyond the face of the wharf.

Patent ce-
ment
wharfs.

(861.) *Patent stone or cement wharf*.—A wharf wall of this kind has been formed 270 feet in length, at the East end of His Majesty's dock-yard, Woolwich. The operation was commenced by driving a few piles, which are intended to be left as defences to the wall, as in the usual stone wharfs; against these pilings planks were temporarily nailed, the back of which corresponded with the intended face of the wall, and behind these was thrown in the cement, mixed as hereafter described, which almost immediately set and became converted into an artificial stone, and being formed to represent stonework can scarcely be distinguished from a real stone wall; any given length being thus finished, the planks are removed, put up in another part, till this is also finished, and so on till the Work is completed. At certain intervals, instead of the stone cement thus formed, layers of artificial blocks of the same material are intro-

duced, of which also school-houses, churches, &c. have been built. These artificial stone blocks are formed by casting the cement into wooden boxes made to the required size and shape, and which when removed differ very little in appearance from actual stone. As, however, it would be improper to trust too much to their tenacity, the common mode of lifting and lowering by the *lewis** is avoided, and holes are formed through them by an iron pin fixed in the mould or box, by means of which, or by slings, the stones may be lifted, lowered, and adjusted.

In order to obtain the best information relative to this novel practice, the writer applied to G. L. Taylor, Esq. the Admiralty architect, under whom the Work above described was constructed, and some other important applications of the patent cement had been made, and he has obligingly furnished the following sketch.

"The patent stone or concrete is composed of clean gravel and sharp sand, and *lime* of the best quality ground to an impalpable powder; by using it *fresh* with *hot* water the utmost strength is obtained, and it sets immediately; enclosed in boxes of any shape, by working up the face which is to appear, ashlar or mouldings are formed exactly resembling stone, and, if properly done, possessing the qualities thereof. The proportion of lime to gravel depends on the quality of the lime, and in that and the method of mixing and using them, in which much judgment and attention are requisite, depends the quality of the material. It is applicable to house-building, and possesses the advantage of having both the exterior and interior of the walls finished as the Work proceeds, leaving only ceilings to dry, and the building may be made to possess an architectural character at less cost than the plainest brick one. I have erected a school at Lee, a fac-simile of the Propylæa at Athens, with this result.

"At Chatham, I caused a new foundation to be put under the whole of the walls of a storehouse 540 feet in length, in four months. The building had been erected about 40 years on timber sleepers and plank which had decayed; we had to excavate on each side of the walls to a depth of from 16 to 26 feet, to take out the decayed timbers, from 2 to 6 feet in height, and 6 to 7 feet in width. The concrete was put in in a liquid mass to within a foot of the bottom of the old walls, when a large slate was bedded, and that foot was *pressed* in by an iron frame with 2 strong screws on each side of the wall, in lengths of 4 feet, and the weight of the superincumbent wall, 50 feet high, 5 feet thick, was taken on the material the next day without the least subsidence.

"In another building at Chatham, which had settled, we raised the part up bodily 3 inches by the same method. At Chatham we are also constructing a dock of

* It may be proper for the sake of some of our readers to describe this very ingenious apparatus, which is represented in fig. 4, plate lv. It is used in lifting large blocks of stone. A hole is cut in the upper face to the depth of 3 or 4 inches, widest at bottom. There are three pieces of iron with a hole through each to receive the pin of the tackle *s*. The pin being withdrawn, the two side pieces are dropped in the hole, and their wedge-formed sides brought to the sides of the hole. The straight centre piece is then dropped in and the pin inserted. Now, the tackle being applied to the hook, the weight of the stone presses the wedges against the sides of the hole, and the block is borne up with safety, although always to the terror of the inexperienced looker-on.

Manufactures.

this material, the sides are done in mass, the bottom is laid as masonry in large blocks cast in boxes, and all lined with granite. The expense of this dock is barely a tenth of the amount they have usually cost.

"At Woolwich we constructed, a year ago, a river wall 270 feet long, 26 feet high, 7 feet broad at bottom, 4 feet at top. This was done without any protection, the river flowing on it every tide; we commenced by putting in the material behind boards, but latterly adopted the plan of forming the face with blocks cast in boxes set in masonry and backed with the material in mass. At Woolwich also a dock is constructing of the same material. The springs being very strong have occasioned several experiments to be made; we have now overcome them by adopting the method of setting the bottom with two layers of cast material as masonry, by which means the running water does not extract the lime as it does when the material is in a liquid state.

"The foregoing is the experience I have had of this material; for any further information I must refer you to the patentee, Mr. Ranger, Stangate, who had applied it to buildings before I knew him, but the application to river walls, docks, and undersetting were of my adoption."

MECHANICAL PROCESSES AND MANUFACTURES.

This head includes a very great variety of operations; indeed, nearly every mechanical Art might be given under so comprehensive a title; but we propose to confine it only to those which belong to the manufacture of articles formed of metal or fibrous substances: such as do not fall under one or other of these divisions, will be given under the head Miscellaneous Mechanical Arts.

Mechanical Processes in Metals.

Button-making.

Button-making.

(862.) To follow out strictly the arrangement above stated, we should have to treat here only of the manufacture of metal buttons; whereas buttons are made of a great variety of substances. In most of them, however, metal is employed to form the shank; and even such as have no metal in them we shall give under the present Article.

The different kinds of buttons are very numerous, being formed of the following substances; *i. e.* metal buttons, including steel, copper, plated, or gilded, white metal, gold, silver, &c., glass, stone, mother of pearl, ivory, horn, bone, tortoiseshell, paper, and leather. Many other substances are also manufactured into buttons; besides moulds of different kinds, which are afterwards covered by silk, mohair, horse-hair, &c. It will, of course, be impossible for us to enter minutely into a description of all these processes; we propose, therefore, to confine our principal description to those made in greater numbers, and in which Machinery is more generally had recourse to.

Gilt buttons: cutting the blanks.

Gilt buttons.—These are formed of copper, with a little alloy of zinc. The metal is first taken to a rolling-mill, and reduced to the proper thickness for the button, and its edges properly squared off with shears. The rolling-mill and shears employed for this purpose differ only in size from the Machines described under Shears (Art. 449.) and Rolling Mill, (Art. 541.) and are commonly worked by hand; these, therefore, require no particular description.

VOL. VIII.

The copper thus prepared is brought to the button manufactory, and cut out into blanks of the intended size of the button by means of a small fly-press. This work is commonly performed by women or boys, who acquire a dexterity in the operation which is truly astonishing to a stranger. Taking the sheet of copper in one hand, the other being free to urge the flyer of the press, the copper-plate is pushed forward, and the blanks successively cut out, both in the length and breadth of the plates, till the part remaining is a complete skeleton, the circular holes being separated from each other only by mere lines of metals.

(863.) *The fly-press* varies considerably in its form, and appears to have received its denomination from being commonly worked with a fly; but in the manufacture of buttons it retains only the name of the fly-press, being worked by means of a lever only, unless, indeed, the slightly weighted handle can be considered any apology for the denomination; in other respects, however, the Machine is the same. Fig. 1, 2, &c., plate lvii., is the representation of a very usual form of fly-press, as employed by button-makers, and for other purposes. The frame is cast-iron; in the upper part of this frame is a screw box fitted, and the screw B passing through it. The top of the screw is fixed to a curved handle *a b c*, furnished with a weight *c*, which acts as a fly when the handle is turned round by a boy or woman sitting before a bench or table, on which the press is fastened by two bolts passing through projecting pieces D D of the iron frame. At *e* a piece of iron is fastened, projecting from the iron frame, and supporting a socket for the square iron slider *f* to slide up and down, and to avoid any shake in its motion. The socket can be at any time made to fit the slider by the four screws seen in the side, fig. 3, which draws the two halves of the socket together. The upper end of the slider *f* is connected with the screw B, by a joint which allows the screw to turn round independently of the slider, but obliges the latter to accompany the screw in its vertical motion, either ascending or descending. At the lower end of the slider *f* the punch or tool *g* is fastened by a clamp screw; it acts in combination with another tool *h*, called the die, fixed below it in the frame by four screws *i*, (shown in fig. 3,) which allows of its adjustment in the true position beneath the tool. The lower tool or die is fitted into a block which is held by four screws; and by this means the die can be quickly changed without disturbing the press. The upper tool can be removed in the same manner, by releasing the clamp screw, which holds it in the slider *f*. These are the essential parts of any fly-press; but, generally, for the purpose of the button-maker, they are less massive than is here described, although, in principle, there is no difference. With respect to form there is great variety; that above described may be considered the most simple. The operator (which is, as above stated, generally a woman or a child, where the object is only to cut the blanks for buttons) is seated on stands before the press, holding the plate of copper in the left hand over the lower hole, while he draws the handle towards him with the other, which turns the screw, urges the punch down upon the metal, and forces out the blanks as above described, which fall into a drawer below, placed there to receive them.

(864.) The next step, or at least the collateral step with cutting the blank, is that of forming the shank, which is made of either brass or iron wire. The old method of

Mechanical Processes.

Plate lvii.
Fig. 1, 2, 3.

Forming the shanks.

Manufac-
tures.

Plate lvii.
Fig 4.5, 6,
7.

Fixing on
the shanks.

Dipping.

Gilding.

effecting this was to fix in a lathe a steel bar of a form in its section resembling fig. 4; this bar being close, covered with successive spires of the wire, as in fig. 5, is removed from the lathe: a long staple-shaped wire (fig. 6) is then introduced, and by means of a long punch or cold chisel a blow is struck along one side, giving to each fold the form shown in fig. 7, and the whole being now cut up the middle, every spire of the spiral is converted into two complete shanks. Such was the usual method of forming the shanks, and it is still very commonly adopted; but frequently now the shanks are formed by a very ingenious little Machine of recent invention, which works by the continuous motion of a winch. Here the wire, of which the shank is made, is brought from a reel to the Machine; and, one end of the same being introduced, the engine draws it in, cuts it to its proper length, and then the two ends are pressed up over a steel pin of the proper size; and a small hammer immediately strikes the ends of the shank a few blows, which flattens them, and facilitates the subsequent soldering; the shank is then slipped off the pin, and another length of wire cut, and so on without intermission; the whole being performed by a woman or boy turning a handle, no skill whatever being required in the operator.

The shanks thus formed are secured to the bottom of the buttons by a small iron or wire clasp, somewhat resembling a pair of tweezers, and a small quantity of solder and resin applied to each. They are then placed on a sheet of iron containing about a gross, and introduced into a very hot stove, where they remain till the workman is satisfied that the solder has melted, and that the shanks are united to the button, after which the edges are smoothed in a lathe.

The next process is what is called *dipping*; that is, a number, consisting of a few dozens, are put into an earthen vessel full of small holes like a colander, and thus dipped into dilute nitric acid to clean them from dirt and rust. They then, according to the best practice, go into the hands of the burnisher, who, in a lathe, burnishes the tops, buttons, and edges with a hard, black stone, got from Derbyshire, secured in a handle like the diamond of a glazier: this he applies to the button fixed in the end of a piece of wood, turned with great velocity by means of a treadle, with which he works the lathe. This is called *rough burnishing*, and is a modern improvement: it is of great advantage, by closing the pores of the metal opened by the acid, so that the gold afterwards to be applied attaches to a smooth surface, which, otherwise, might enter into imperceptible cavities, and be closed up in the body of the button by the final burnishing. When the buttons come from the burnisher they are fit for gilding. This is a very curious operation, and wholly chemical.

(865.) The first process towards gilding is what is called *quicking*, which is effected as follows:—Any number of buttons, perhaps a gross, is put into an earthen vessel with a quantity of mercury, which has been previously saturated with nitric acid; and thus the buttons and mercury are stirred together with a brush till the mercury adheres to the whole surface of the button. These are then taken out and put into what is called a *basket*, though, in fact, an earthen vessel full of small holes, the handle of which the operator holds in his hand, and jerks it with considerable force down towards a wooden trough, (a receptacle for the quicksilver,) till, by repeated jerks, all the loose particles of mercury

are disengaged, leaving a complete continuity over the surface, and giving them the appearance of silver buttons.

The gold, a grain of which will spread over many superficial feet of copper, is thus prepared:—Any given quantity of mercury is poured into an iron ladle, the inside of which has been previously *guarded*, that is rubbed over with dry whiting to prevent the gold from adhering to the iron: into this mercury is thrown the portion of pure gold intended to cover a certain number of buttons. The gold and mercury are heated together in the iron ladle till the workman (whose practice soon enables him to judge) perceives there is a perfect union between them, when he empties his ladle into a vessel containing cold water.

The amalgam being cold is put into a piece of shammy leather, and squeezed till no more mercury will pass through. What passes the shammy contains not the smallest portion of gold; and what remains will be about the consistency of butter, so completely united that every particle of mercury shall contain an equal portion of gold. The amalgam should be then put into an earthen vessel, and a small quantity of nitric acid added, allowing sufficient time for the acid to unite with the mercury. But the buttons and amalgam are commonly introduced first, and a quantity of dilute nitric acid added thereto, so that, for want of a complete union between the mercury and first acid, if there be not a superabundance of acid, there may not be sufficient to carry all the amalgam to the surface of the buttons.

When the acid has had sufficient time to *embrace* (as workmen call it) the mercury, the buttons are introduced, and stirred till the amalgam, carried by the affinity of the acid to the copper, and the tendency which the gold has to extend itself to the mercury with which the buttons have been previously quickened, completely attaches to the whole surface.

The gilding being thus far completed, the next thing is to recover, for subsequent operations, the mercury which has been employed; and the following method is recommended by the author of the above description, *Philosophical Magazine*, vol. ix.

The old practice was, after the buttons had been completely covered with mercury and gold, for the operator to proceed to what was called *drying off*, which was performed thus:—The buttons, to the amount of a few dozens, were put into an iron pan somewhat like a large frying-pan, placed over a fire, and gently shaken, while the operator watched carefully till he observed the mercury begin to flow; upon the first symptoms of which, he took the pan from the fire, and threw the buttons into a large cap, called a *gilding cap*, like a man's hat with a very small brim, but much larger in the crown, made of coarse wool and goat's hair. In this cap, with a circular brush, the buttons were stirred, to spread the gold and mercury while in a degree of temperature nearly sufficient to volatilize the mercury. The buttons were thus again thrown into the pan, placed over the fire, and shaken, while the mercury gently volatilized, when the buttons were again thrown into the cap and stirred with the brush. This process was continually repeated, till all the mercury was volatilized, leaving the gold on the buttons, which appeared again of a yellow colour. By these means the principal part of the mercury ascended the chimney and was deposited on the tops of the houses and about the adjacent neighbourhood, and great quantities were inhaled and

Mechanical
Processes.

Drying off
by the old
method.

Manufac-
tures.

absorbed by the operator, keeping him nearly in a state of salivation, till disease obliged him to desist. Every one who has formerly visited our button-manufactories at Birmingham, and elsewhere, can bear testimony to the emaciated state of the parties, mostly women, employed in this unhealthy process.

Considerable quantities of mercury thus volatilized are found united and collected in small pools in the spouts and gutters on the tops of the buildings. Thus many tons of mercury have been dissipated about the town and neighbourhood, to the great injury of the inhabitants. The poor sweep who has ascended the chimneys has been salivated, and the manufacturer has sustained considerable loss.

New pro-
cess re-
commended.

To preserve a principal part of the mercury thus dissipated, and to prevent, in a great measure, the terrible effects of it on the constitution of the operator, the following process has been recommended by the author above referred to.

Plate lvii.
Fig. 8.

By means of an apparatus similar to the plan delineated in fig. 8, which was first partially and successfully adopted by Mr. Mark Sanders, an eminent button-maker of Birmingham, the principal part of the mercury may be recovered, and the health of the operator greatly preserved.

A hearth of the usual height is to be erected, in the middle of which a capacity for the fire is to be made; but instead of permitting the smoke to ascend into the top of it, made of sheet or cast iron, through which the mercury is volatilized, a flue for that purpose should be conducted backwards to the chimney B. An iron plate, thick enough to contain heat sufficient to volatilize the mercury, is to cover the fire-place at the top of the hearth C. There must be an ash-hole D under the fire-place. The square space E, seen in the fire-place, is the flue which serves to carry the smoke back under the hearth into the chimney B. The door of the fire-place and ash-pit may either be in front, as represented in the plate, or at the end of the hearth at F, which will perhaps less incommode the work-people. It would be of great advantage if the space between it and the iron plate C was covered up with a glass window coming down so low as only to leave sufficient room for moving the pan backwards and forwards with facility. If the sides are also glass instead of brickwork, it would be still better, as the work-people would be able to have a full view of their work without being exposed to the fumes of the mercury, which, when volatilized by heat communicated to the pan by the heated iron plate over the fire-place, would ascend into the top A, appropriated for its reception, and descend into the tub G', covered at top and filled pretty high with water. By this means the hearth would, in fact, become a distilling apparatus for condensing and recovering the volatilized mercury. In the tub G', the principal part would be recovered; for, of what may still pass on, a part would be condensed in ascending the tube H, and fall back, while the remainder would be effectually caught in the tub or cask I, open at the top and partly filled with water. The latter tub should be on the outside of the building, and the descending branch of the tube H should go down into it at least 18 inches, but not into the water. The chimney or the ash-pit should be furnished with a damper to regulate the heat of the fire. The water may be occasionally drawn out of the tubs by a siphon, and the mercury, clogged with heterogeneous matter, may be triturated in a piece of flannel till it passes through, or placed in a pan of sheet iron, like a dripping-pan, in a

sufficient degree of heat, giving it a tolerable inclination, so that the mercury, as it gets warm, may run down and unite in the lower part of the pan. But the mercury will be most effectually recovered by exposing the residuum left in the flannel bag to distillation in a retort made of iron or of earthenware.

Mechanical
Processes.

When the mercury is volatilized from the buttons, or, as the workmen denominate it, when the buttons are dried off, they are finally burnished, and are then finished and fit for carding.

The reader unacquainted with this branch of manufacture will be surprised to learn how far a small quantity of gold, incorporated with mercury, will spread over a smooth surface of copper. Five grains, worth one shilling and three-pence, spread on the top of a gross, that is, 144 buttons, each of one inch diameter, are sufficient to excuse the manufacturer from the penalty inflicted by an Act of Parliament; yet many, upon an assay, are found to be deficient of this small quantity, and the maker fined and the buttons forfeited accordingly. Many hundred grosses have been tolerably gilt with half that quantity; in which case the thickness of gold is only $\frac{1}{214000}$ th of an inch; so extremely far can gold be spread, when incorporated with mercury, over the surface of a smooth piece of copper.

(866.) *Plated buttons.*—These are stamped by the fly-press, as above described, but are cut out of copper plated with silver on one side, rolled at the flattening-mill. The copper side is placed uppermost in stamping, and the die or mould, through which they are stamped, is chamfered at its edge to make the silver turn over the edge of the button. The backs are stamped in the same way as the gilt buttons, but the shanks are soldered on with silver solder, and heated one by one in the flame of a lamp or gas-light with a blow-pipe urged by a pair of bellows. The edges are then filed round in a lathe, care being taken not to remove any of the silver which is turned over the edge. They are next dipped in acid to clean the backs, and boiled in cream of tartar and silver to whiten the backs, after which they are burnished, the backs being first made clean by a brush held against them as they revolve in the lathe. The burnishing is performed exactly as that of gilt buttons above described.

Plated
buttons.

Cup or convex buttons, either plated or gilt, are made of two pieces, viz. a common flat button with a shank and a small hemisphere fixed on in front. These hemispheres are punched out by the fly-press, and then the inside is turned in a chuck lathe to receive the edge of the plain button made as before described; when put in its place the edge of the cup is burnished down over it to hold it fast. These buttons are afterwards gilt and burnished like the plain ones as above described. But tons with a hoop or projecting ring round their edges are made in the same way.

Cup but-
tons.

White metal buttons are formed of a common white metal, a compound of brass, pewter, &c. The metal is not here rolled into plates, as described in the last Article, but is cast into moulds in which the shank of iron wire is previously placed. The mould is formed by a metal pattern, consisting of a great number of circular buttons, connected by small bars from one to the next to form a passage for the melted metal. An impression from this pattern, which frequently contains as many as twelve dozen buttons, is taken in the sand in the usual manner, and the shank is pressed into the sand in the centre of each impression, the part which is to enter the metal being left projecting above the surface of the sand.

White
metal
buttons.

Manufac-
tures.

The metal is now melted and cast into the mould, a little zinc being commonly added to cause it to flow more freely, thereby to fill the mould more completely, and to produce a sharp casting. The buttons, being thus cast and taken from the mould, are cleaned from the sand by brushing; they are then separated from each other by breaking the small metallic bars which unite them, and taken to another workman at a lathe, who inserts the shank of each button into a chuck of a proper figure, in which it is retained by the back centre of the lathe being pressed against the button with a spring. Here the circumference is reduced to a proper circle, and the button is instantly released by the workman pulling back the spring, and another button is introduced. A third workman turns the back of the button smooth in a chuck lathe, and makes the projecting part round the shank true, and a fourth workman renders the face of the button smooth by placing it in a chuck and applying the angle of a square bar of steel across its centre. As it is not thought necessary to make the surface of the button perfectly flat, the tool is only held in the hand, which greatly facilitates the operation, as by this means any small deviation from the truth is followed much more readily than the surface could be cut if the tool was fixed in a rest. The next operation is polishing the button. Here the shank is held in a piece of wood, and the face is rubbed on a piece of board covered with leather, and spread with powdered rotten-stone and oil, and afterwards with a finer powder. The last polish is now given by applying the button lightly to a flat surface of a circular board, covered with soft leather, turned by a lathe, and dressed with exceedingly fine powder of rotten-stone. These polishings are generally performed by women; and the buttons are now finished, except that they have still to be boiled to render them white. For this purpose melted tin is poured into cold water and by this means granulated. A quantity of cream of tartar diluted with water is put into a boiler and tin added to it, a part of which is dissolved by boiling, and the buttons being let down into it on a wire grating, part of the tin attaches itself to the surface of the buttons, whereby they are rendered white while they retain their former polish. In this state they are placed on a card for sale.

Different
description
of shanks.

(867) We have hitherto described the shanks as they are commonly formed, but different methods and forms have been proposed, of which the following is the most recent, as also by far the most simple. Here the disc or face may be of any of the substances usually employed in button-making, there being nothing peculiar but in the form of the shank; this part is made to project from the back of the button, it has no eye to be turned over and sewn to the cloth, but is made straight and of some thickness. It may be made out of the same piece of metal as the button, or it may be made separately and rivetted on to the back. The end of the shank is a small projection from the shank as the latter is from the button. To this last projection a washer is fitted, so that, instead of sewing on as usual, a hole is made in the clothes, the shank passed through, the washer is then applied, and with a small hammer the end of the shank is rivetted so as to overlap the end of the washer, and thereby to secure the button tightly in its place. It is, of course, exactly the same thing whether the rivet is placed inside or over the button, but, in the latter case, the rivet should be made ornamental. Other plans are suggested by the patentee, such as to make the shank of the washer a

tube, and the shank of the button a rod to fit it, &c. Mechanical Processes. It is considered that by this means of putting on the button it will fix tighter and the clothes fit better than according to the common method.

Other patents for buttons, shanks, &c., will be found in vols. xii., xiii., old series of the *Repertory of Arts*, and in several volumes of the second series. The patent above described is from vol. lix. of the same Work.

Hitherto the buttons have been described as plain gilt or plain plated, but the surface of both is sometimes ornamented with particular figures, concentric and eccentric circles, or portions of circles in every variety of combination. This is done sometimes in a lathe by applying a milling tool to the face; this tool is a small steel roller with the intended pattern engraved on its periphery, it is held in a simple slide rest which thus makes the circles on each successive button of the same size, and occupying the same part, to the number required, when the pattern may be changed by changing the tool.

Another way of ornamenting the face of buttons is by means of a small Machine furnished with wheel-work, so contrived that, a button being placed upon it and a handle turned, it is made to revolve either concentric or eccentric with the central wheel of the Machine. There is also a small hammer like a rivetting hammer pressed by a spring; this is successively lifted and forced down by the spring as the Machine is turned, and by the blow a small indentation is made on the button, either a point or line, and as by the structure of the Machine the button may be placed eccentric in any degree, an immense variety of patterns may be formed by the slightest change or adjustment of the parts.

(868.) *Glass buttons.*—These are frequently wholly composed of glass variously coloured, in imitation of opal, topaz, and other stones. The method of forming them is as follows: the glass is kept in a state of fusion, and the button nipped out of it, while in a plastic state, by a pair of iron moulds, like those used for casting pistol shot, adapted to the intended form of the button, the shank being previously inserted into the mould, so as to become imbedded in it when the glass is cold.

Mother of pearl buttons.—The disc of mother of pearl, being already formed to the proper size and thickness of the button, is drilled in the centre and slightly under-cut. The shank, then, formed as already described, being driven in with a steady stroke, its extremities extend on being driven against the bottom of the hole, and become thus firmly rivetted into the button. To this kind of button are frequently added fossil stones, usually attached to the surface by isinglass glue; steel studs are also sometimes rivetted into buttons of this and various other kinds.

Shell buttons are those which consist of a back made of bone without any shank but corded with catgut, and covered in front with a thin plate of metal struck with a die. The backs are cut out with a brace or stock, the bit of which is a sort of crown or trepanning saw, and the four holes through which the catgut passes are drilled according to the method described in the following article. The backs are then corded by children, who tie the catgut on the inside; the cavity is then filled with melted rosin and the metal shell applied warm. The button is then pressed between two centres in a lathe, described also in the following article, and being thus forced together the shell is burnished round the back during the revolution by a small burnisher. The

Manufactures.

Pl. lvii.
Fig. 9

method of punching out the concave shell of these kind of buttons is as follows: first, small circles are cut out from the plate in the manner already described for plain gilt buttons. This circle of metal being placed over a die of the proper form, shown in fig. 9, is forced through by the end of a tool or punch K, which being smooth and of a spherical figure causes the plate to assume the same form, which passing through the die into a drawer beneath is in a state fit for use; the aperture of the die L being exactly such as to admit the tool to pass encompassed by the thickness of metal. The upper side must not be left sharp, but rounded off so as not to cut, but simply to bend, the metal in passing through it; the circle of metal must also be larger than the hole, in order that it may rest over it, and be large enough to form the cup or spherical segment as shown at s in the figure.

Horn buttons.

(869.) *Horn buttons* are made either with or without shanks, the latter being commonly called sailors' buttons; in this case the surface of the button is concave, and four holes are pierced through the sunk part for sewing them upon the clothes, the thread being protected from the wearing to which it would be exposed but for the projecting edge of the button. These kind of buttons, although always known under the term horn, are, in fact, formed from cow-hoofs, by an ingenious process of pressing them into heated iron moulds. The hoofs are first prepared by being boiled in water till they become soft; they are then cut into parallel slips by a cutting-knife, which is a blade with a long handle at one end, and jointed to the bench by a hook and eye at the opposite extremity, after the manner of a patten-maker's tool, and which, as in that case, acts as a lever in cutting the horn placed beneath its edge. The slips being the width of the intended buttons are cross-cut into small squares, after which, the angles being taken off, they are reduced to an octangular shape nearly the size of the intended buttons. The next process is to dye them black, which is done by dipping them into a vessel of water impregnated with logwood and copperas. They are then left to dry for about a week, when they are in a proper state for pressing. This is performed as follows: two iron cheeks are provided, each having six, eight, or more small steel dies fixed to it, each die containing the intended impression of the button embossed on it; these plates or cheeks are connected by a long handle to each, which open and shut like a bullet-mould, and when shut the pairs of dies exactly correspond. The workman being provided with a sufficient number, nine, ten, or twelve, of the pairs of moulds, arranges them in an oven or furnace till they become heated somewhat above that of boiling water. A piece of horn cut as above described is then placed above each impression in the mould; this is now shut and held in close contact by being placed in a small screw-press upon the work-bench for a few minutes till the horn is heated and softened. The mould is then removed to a powerful screw-vice, which consists of two very heavy cheeks drawn together by a screw in the usual way, differing only in its size from the common vice, but placed somewhat otherwise, merely for convenience in bringing on the pressure. The mould with the horn in it being placed between the cheeks, and brought nearly central, is pressed so violently, by the combined power of the screw and lever, that the horn is indented with the exact patterns formed in the mould; it is then left to cool, which requires about twenty minutes, more or less, according to

circumstances. At all events the horn must remain in the mould till it is cold, as otherwise it would go from its figure when removed. Nine presses are generally arranged round the stove, which give constant occupation to one workman.

Mechanical Processes.

The buttons being removed, some edges are left which did not enter the dies; these are now clipped off by shears; the button is then placed in a lathe, and filed smooth and round. The method of performing this requires some explanation. The lathe in which the work is performed has two spindles; both are turned with the same velocity by straps from two equal foot-wheels on one axle; the ends of the two spindles come in contact, and have each a chuck with a cavity for the reception of the button. One of these spindles is pressed forward with a spring, and which thereby holds the button fast between the two while it is turned round and its edge filed smooth. This is very quickly done; the spring is then pressed back by a lever provided for the purpose, while the spindle is still in motion; the button immediately falls out into a box beneath; another button is put on, the spring again relieved, which, as before, brings the chucks together, and holds the button between them till it is in its turn relieved, and so on with very great rapidity.

We have in the above description supposed the operation to relate to sailors' buttons without shanks; the work is not, therefore, completed in the above process, it still remains to form the holes for the purpose of their being sewn on the clothes. These are made by means of a lathe having four spindles parallel to each other, and all turned by the same foot-wheel by means of two straps, each turning two spindles. These spindles, however, could not be brought sufficiently near to each other, in consequence of the pulleys upon them, to make the holes so close as they are required to be. Each of them has, therefore, a hook at the end, by which it is connected with another spindle, and these four are now made to incline towards each other so as to pass through an iron cheek or standard in which the four holes are brought to their proper distance, and their points, which project a little way through, are there formed into small drills. The buttons are now successively placed in a concave rest, and thrust against the drills by a piece of wood; the four holes are thus made in an instant, another button is then drilled, and so on. The spindle, having freedom by means of the hooks, may be brought to any distance; it is, therefore, only necessary to change the standard in order to change the distance of the holes according to the size or the intended pattern of the button. A little roughness is produced on the surface of the button by the drilling, which is removed by shaking a number of them together in a flannel bag.

At present we have not spoken of those horn buttons that are furnished with shanks. In these the shank is inserted before pressing by children, by drilling a hole to receive them; the mould also has a hole to receive the shank, and in the moulding, which is performed precisely as above described, the horn is so pressed against the shank as to secure it very effectually in its place.

Coining.

(870.) Before entering upon an explanation of the mechanical operation of coining it may be well to give a sketch of the history of the nature and value of the

Coining.

Manufac-
tures.

different kinds of coinage which have been at times in circulation in Great Britain, and of the relative value of the two principal metals, gold and silver, at different periods.

Usual alloy.

Gold and silver, in their pure state, are too soft and flexible to be formed into coins; they must therefore be alloyed with some other metal or metals, and in this Country they are both alloyed with copper, silver, &c., in the following proportions *viz.*, pure gold 22 + 2 copper = 24, the alloyed metal being supposed to be divided into twenty-four parts, called carats; and it is said to be twenty-two carats fine, that is, of twenty-four parts the pure gold is to form twenty-two. The alloy of silver consists of thirty-seven parts of pure silver and three of copper, and its fineness may therefore be expressed by the fractions $\frac{37}{40}$. This proportion for the alloy of silver coin, which was at the time the only standard, was first fixed in this Country in the time of Richard I. by certain persons from the Eastern parts of Germany, called Easterlings, and hence, by contraction, is said to have arisen our word sterling, to imply of proper standard value: it was also the name originally given to the silver penny.

Experi-
ments to de-
termine the
best alloy
for coin.

(871.) The alloy used in standard gold having been fixed long before that precision was introduced into the Arts which has place at present, it became a question with the British Government, about the commencement of the present century, whether the above proportion was the best that could be devised for preventing the wear and gradual depreciation of weight which our gold coin was known to be subject to; and accordingly a Commission was appointed to inquire into various questions relating to the hardness, ductility, specific gravity, and other circumstances requisite for determining the best alloy for the purpose of coinage. This Commission called to their aid the able assistance of the Honourable Mr. Cavendish and Mr. Hatchett; and the latter, in 1803, gave in the *Philosophical Transactions* an interesting account of the experiments which had been instituted in order to enable him and Mr. Cavendish to make their report. Alloys were made of gold with thirteen different metals, but it appeared from them that, agreeably to general practice and opinion, only two of them are proper for the alloys of gold coin, namely, silver and copper, as all the others either considerably alter the colour, or diminish the ductility of the alloy. In respect to the latter quality the metallic substances that were employed appeared to affect the gold in nearly the following decreasing order:

- | | |
|---------------|-------------------------------------|
| 1. Bismuth. | } These are nearly equal in effect. |
| 2. Lead. | |
| 3. Antimony. | |
| 4. Arsenic. | |
| 5. Zinc. | |
| 6. Cobalt. | |
| 7. Manganese. | |
| 8. Nickel. | |
| 9. Tin. | |
| 10. Iron. | |
| 11. Platina. | The platina not quite pure. |
| 12. Copper. | |
| 13. Silver. | |

Specific
gravity of
different
alloys.

The next subject examined was the specific gravity of different alloys, from which was obtained a long series of results, which we cannot of course give in this place; but the three following on standard gold are important: at the same time Mr. Hatchett admits the extreme diffi-

culty of obtaining perfectly accurate results, in consequence of the unequal union of the different metals in the melted metals. The numbers he has given are, however, as follows:

Gold made standard by silver	17.927
Gold made standard by silver and copper	17.344
Gold made standard by copper	17.157

And it is remarked, that as our gold coin commonly contains silver as part of the alloy, and as at different times this proportion of silver must have been various, particularly when the gold of Portugal, which is alloyed with silver, was brought to the Mint, it naturally follows that, exclusively of any other causes, the specific gravity of our standard gold must occasionally be different according to the relative proportions of silver and copper which compose the alloy; moreover, an exact distribution of the alloy is not very easily made where a large quantity of gold is to be alloyed.

In the regulation of the Mint these discrepancies have been considered, and an allowance has been made for it, which is called the *Remedy for the Master of the Mint*, according to which, when the trial of the *Pix*,* as it is called, takes place before the Lord Chancellor, the Lords Commissioners of the Treasury, &c., for inspecting the standard value of the coinage, the Master of the Mint is held excusable if the imperfection or deficiency of the coin in the aggregate is less than a sixth part of a carat, equal to forty grains, of fine gold in the pound, or the hundred and thirty-second part of the value.

The next experiments were made on the comparative wear of different alloys, both on plain pieces and those with raised figures, milled edges, &c.; and with a view to these a machine, suggested by Mr. Cavendish, was constructed, so as to expose the pieces to different degrees of friction; but here again it was found that the present alloy of our standard coin was amongst the best that could be suggested to prevent that wear which had been observed, or rather which was assumed, to be the cause of the depreciated weight; for the reporter seems decidedly of opinion that the diminution complained of is not the result of fair wear. The paper concludes as follows:—"Upon a comparison of the different qualities of the three kinds of standard gold which have been mentioned (*i. e.* gold with silver, gold with silver and copper, and gold with copper) it appears, strictly speaking, that gold made standard by silver and copper is rather to be preferred for coin; but, as gold made standard by copper alone is not very much inferior in its general properties, it may be questioned whether the few advantages which are thus gained will compensate the additional expense of the silver required for half the alloy; and, indeed, any extraordinary addition of silver appears to be the less necessary, as there is commonly some silver in the gold which is sent to the Mint, which, being reckoned as part of the alloy, contributes to produce those beneficial effects which result when silver is purposely added.

"From a general view of the present experiments

* The *Pix*, in the language of the Mint, is a box in which a small proportion or sample of the coins struck at the Mint is reserved, in order to be assayed and compared with a check piece or standard coin kept in the Exchequer for the occasion. This operation, which is called the *Trial of the Pix*, is performed with great ceremony, and with much exactness, in the presence of the Privy Council, the officers of the Mint, and a jury of the Goldsmiths' Company. It is said there is no instance on record in which the coin thus tried have been found to vary from the full standard.

Mechanical
Processes.

Remedy of
the Mint.

Wear of the
coin.

Manu-
tures.

there does not appear to be any very great or remarkable difference in the comparative wear of the three kinds of standard gold, all of which suffer abrasion slowly, and with much difficulty, and (as it has been already observed) the difference of wear between the two last mentioned is certainly but inconsiderable. For these reasons, and from the consideration of every other circumstance, it must be evident that the extraordinary loss which the gold coin of this Kingdom is stated to have sustained within a certain limited time, cannot, with even a shadow of probability, be attributed to any important defect in the composition or quality of the standard gold; and all that can be said upon this subject is, that some portion of this loss may have been caused by the rough impression and milled edge now in use, by which each piece of coin acts and is acted upon by the others in the manner of a file.

"The loss thus occasioned cannot, however, be considerable; for the quality of the present standard gold is certainly that which is well adapted to resist abrasion, especially in the case of the friction of coin; and this is strongly corroborated by the observation of bankers and others, who are in the habit of sending or receiving large quantities of gold coin from any considerable distance. When a number of guineas, rather loosely packed, have been long shaken together, by the motion of a coach or other carriage, the effects of friction are observed chiefly to fall upon only a few of the pieces. But it is not a little remarkable that although these are often reduced nearly or quite to the state of plain pieces of metal or blanks, yet, upon being weighed, they are found to have sustained little or no loss; and from this it appears that the impressions have been obliterated, not by any actual abrasion of the metal, but by the depression of the prominent parts, which have been forced into the mass, and become reduced to a level with the ground of the coin. Pieces of hard gold would not so easily suffer by depression; but the real loss would probably be greater, they being, in the case of the friction of coin against coin of similar quality, more susceptible of abrasion.

"Upon the whole there is every reason to believe that our gold coin suffers but little by friction against itself; and the chief cause of natural and fair wear probably arises from extraneous and gritty particles, to the action of which the pieces may occasionally be exposed in the course of circulation. But still it must be repeated that the united effects of every species of friction to which they may be subjected, *fairly and unavoidably*, during circulation, cannot produce any other wear than that which is extremely gradual and slow, and such as will by no means account for the great and rapid diminution which has been observed in the gold coin of this Country."

As the general results of each part of this inquiry have been noticed at the close of the different sections, a regular recapitulation would be superfluous. We may, however, observe that the experiments on the various alloys of standard gold concur with established practice and opinion to prove that only two of the metals, *viz.*, silver and copper, are proper to be employed in the reduction of fine gold to standard for the purpose of coin; but, at the same time, it must be allowed that the phenomena exhibited by arsenic, antimony, zinc, cobalt, nickel, manganese, bismuth, lead, tin, iron, and platina, are in many respects remarkable, and demonstrate the utility of a regular experimental investigation of metallic alloys.

Mechanical
Processes.

The contents of the second section show that numerous causes influence the specific gravity of metals; and amongst these it has been long ago observed that some metals, when added to others, generally produce contraction in the bulk of the mass, or an increase of specific gravity, but that other metals produce effects which are precisely the reverse. This, to a certain extent, is unquestionably true; but it does not follow that each metal which produces contraction or expansion, when added to others, should (as some have supposed) constantly produce similar effects, corresponding to the relative proportion of that particular metal; for we well know that some metals, in like manner, promote the fusibility of others in a much greater degree than could be expected from their natural or inherent fusible property; but then the maximum of this effect is produced by certain proportions of the different metals, and suffers diminution by any variation in these proportions. It appears, therefore, that this great degree of fusibility is a property peculiar to the compound, which cannot immediately be attributed to either of the component metals; and we are much deceived if those alterations in specific gravity, which, in like manner, are observed in the various metallic compounds, will not admit of a similar explanation; for, in respect to the contraction or expansion which takes place in consequence of combination, we may believe that there is a maximum of this contraction or expansion dependent on a certain relative proportion of the different metals.

The experiments on the comparative wear of gold, which are described in the last section, were attended with considerable difficulties; for this reason the conclusions have been founded only upon such facts as were uniformly the same under every circumstance. These general conclusions have been already fully stated; but we may again observe that gold of moderate ductility is (all things being considered) the best adapted to the purpose of coin, and that the real wear of such coin is, in all probability, very slowly effected; so that a long period of time must elapse before any considerable diminution in weight can be perceived.

The experiments contained in these three sections were limited to standard gold; and, allowing that some curious and instructive facts have been discovered, still more might have been expected from an extension of such experiments to gold variously alloyed in every possible proportion. But an immense addition to Metallurgical Science would, in all probability, be derived from a comparative investigation of the whole of the known metallic substances, formed into binary, ternary, and such like combinations, proceeding from the most simple to the most complicated, and accompanied by accurate observations on the lustre, colour, ductility, hardness, specific gravity, and fusibility of the compounds.

Our actual knowledge of the properties of metallic mixture is certainly very imperfect, and has by no means kept pace with the rapid progress of modern Chemistry. Few additions have been made to the compound metals employed by the Ancients: the various mixtures of gold and silver called *electrum*, those of the Corinthian metal, the varieties of bronze, the compound of copper and zinc, now called brass, the metal for specula, the metal called *argentarium*, (in some measure answering to our pewter,) the art of plating and of turning, and the process of amalgamation, evince how great a progress had been made by the Ancients in the mixing and working of metals.

Manufac-
tures.

Much, however, remains to be done, and much may be expected from a regular and systematical series of experiments on the properties of compound metals. For, exclusively of the immediate application of many of the alloys to economical purposes, it cannot be doubted that Science will derive other considerable advantages; our ideas concerning the properties of the metals, whether simple or mixed, will be much enlarged; and clouds of errors, with the traditionary prejudices which as yet shade this branch of human knowledge, will be dispersed.

Coinage in
England.

(872.) The first English gold coin of which there is any account was struck in the year 1257, by order of Henry III. It was of pure gold, weighing two pence or two sterlings of silver, and was to pass for twenty pence, whereby the relative value of gold and silver was as ten to one. The weight of this piece was about the third part of our present sovereign.

The next gold coinage was in the year 1344, when the gold *florin* was struck, which took its name from Florence, where it had been first coined in 1252. In German it was called a *gulden*, and in Holland a *guilder*, indicative in both cases of its quality; although the present guilder or florin is a silver coin.

Relative
value of
gold and
silver

The guinea, now supplanted by the gold pound or sovereign, when first coined, passed for about twenty shillings, but its relative value to that of silver was not fixed, so that it varied in value from twenty to twenty-one shillings, but was in the reign of Charles II. fixed in its value in comparison with silver, and from that time it always passed for twenty-one shillings, which made the relative value of gold and silver as $15\frac{1}{2}$ to 1,

which it still maintains, whereas we have seen that, when gold was introduced into this Country as money, the relative value of the two metals was assumed to be as 10 to 1. This relative value has, however, varied very considerably in different ages in nearly all Countries. According to Herodotus the relative value of the two in Persia was as 13 to 1
In Greece ancient historians state it as 12 to 1
In the time of Alexander the Great it was 10 to 1
In Rome, to the time of Julius Cæsar 10 to 1
but it afterwards was reduced to $7\frac{1}{2}$ to 1

Mechanical
Processes.

In England, up to the time of the discovery of America, it was as 11 to 1
..... 10 to 1
..... 9 to 1

In Spain and Portugal, in the time of Sir Isaac Newton 16 to 1

Other parts of Europe 15 to 1
And the last proportion, with very little variation, is still maintained in most parts of the Continent.

During the wars with France, from 1797, when the Bank Restriction Act was passed, to 1819, great fluctuation took place in the market value of gold, and nearly all gold coin was banished from the Country; the silver coin was also much depreciated in value, either through wear or unfair means, so that it would be useless to attempt any comparison during that period; but since the return of money payments the prices both of gold and silver have been nearly stationary, as appears from the following Table, which shows the market price of both metals, and the quantity and amount of each coined at the Royal Mint for each year, from 1820 to 1831 inclusive.

Years.	Months.	Price of Gold in Bars, per Ounce.	Price of Silver in Bars, per Ounce.	Gold coined.	Silver coined.	Total coined.
		£. s. d.	s. d.	£. s. d.	£. s. d.	£. s. d.
1820	February.	3 17 10 $\frac{1}{2}$	5 1 $\frac{1}{2}$	949,516 0 10	847,717 4 0	1,797,233 4 10
	August.	3 17 10 $\frac{1}{2}$	5 0			
1821	February.	3 17 10 $\frac{1}{2}$	4 11 $\frac{1}{2}$	9,520,758 13 10	433,686 0 0	9,954,444 13 10
	August.	3 17 10 $\frac{1}{2}$	4 11			
1822	February.	3 17 10 $\frac{1}{2}$	4 11	5,356,787 12 6	31,430 7 1	5,388,217 19 7
	August.	3 17 6	4 11 $\frac{1}{4}$			
1823	February.	3 17 6	4 11 $\frac{1}{2}$	759,748 10 0	285,271 16 0	1,045,020 6 0
	August.	3 17 6	4 11			
1824	February.	3 17 6	4 11 $\frac{1}{2}$	4,065,075 0 0	282,070 16 0	4,347,145 16 0
	August.	3 17 6	4 10			
1825	February.	3 17 9	5 0 $\frac{3}{4}$	4,580,919 0 0	417,535 16 0	4,998,454 16 0
	August.	3 17 10 $\frac{1}{2}$	5 1			
1826	February.	3 17 6	5 1	5,896,461 7 6	608,605 16 0	6,505,067 3 6
	August.	3 17 6	4 10 $\frac{3}{4}$			
1827	February.	3 17 6	4 11 $\frac{1}{2}$	2,512,636 17 6	33,019 16 0	2,545,656 13 6
	August.	3 17 6	No price.			
1828	February.	3 17 6	Do.	1,808,559 2 6	16,288 3 0	1,024,847 5 6
	August.	3 17 6	Do.			
1829	February.	3 17 10 $\frac{1}{2}$	4 11 $\frac{7}{8}$	2,446,754 12 6	108,259 16 0	2,555,014 8 6
	August.	3 17 9	4 11 $\frac{5}{8}$			
1830	February.	3 17 9	No price.	2,387,881 2 6	151 16 0	2,388,032 18 6
	August.	3 17 10 $\frac{1}{2}$	4 11 $\frac{1}{4}$			
1831	February.	3 17 10 $\frac{1}{2}$	No price.	587,949 14 5	33,696 5 8	621,646 0 1
	August.	3 17 10 $\frac{1}{2}$	5 0			
Total.....				£ 40,073,047 14 1	3,097,733 11 9	43,170,781 5 10

Manufac-
tures.
Process of
coining.

(873.) *Process of coining.*—The Art of Coining is of great antiquity, as is evident from the many ancient coins still preserved in our museums, but it was performed only by hand, with a hammer, and was a slow and imperfect process, proofs of which are frequently exhibited by the impressions on the reverse sides not being opposite to each other. The hand hammer, however, was the only method known till the time of Henry II. of France, in whose reign the coining-mill was first invented by Antonine Brucher, a French engraver, the first money struck by a mill or press bearing the date 1553. Like most other important inventions, however, many objections were made to it, particularly to the expense with which it was attended, and it was accordingly, after having been in use for about thirty-two years, laid aside by Henry III., in 1585, and was not again revived in that Country till the year 1645, by Louis XIV. The press was, in the interval, introduced into England by Elizabeth, in 1562, but, as in France, it was afterwards laid aside, and the process by hammer again had recourse to. In the year 1662 the mill was again put in force, and no other means have been since employed, although the machinery itself has undergone great changes, and has received various improvements.

Puncheon,
die, and
matrix.

The Ancients employed a sunken die, but different from the present, insomuch as the sunken part was made by the cutter or engraver; whereas the modern practice is to employ a puncheon, which is of highly-tempered steel, and on this the impression intended to be made on the coin is cut in relievo. It is then stamped on another piece, called the matrix, which is also of steel, four or five inches long, square at the bottom, and round at the top. The moulding of the border is afterwards added on the matrix with small sharp steel puncheons. When thus completed it forms the die. This saves much labour in repeatedly engraving, for it frequently happens, with striking the first coin, the die breaks, and, but for this provision, a new engraving would be required; moreover, as it would be almost impossible to engrave several dies all exactly alike, but one die could be employed at a time without introducing great variety, and thus facilitating the object of the false coiner. It is not certain when this improvement was first introduced, although it is certainly an important one in the Art of Coining.

Milling the
edges.

Another improvement in the coiner's Art, of somewhat modern date, is that of milling or ornamenting the edges, which was intended as a protection against what was called clipping and filing the King's coin—a fraudulent process, by which the weight and value of the several pieces have been much reduced; other means, however, have been contrived for effecting this object, as appears by the report of Mr. Hatchett, given in a preceding part of this article. It must, however, have contributed in part towards the prevention, and it adds greatly to the beauty and perfection of the coin as a work of Art. Its first introduction at the English Mint appears to have been about the year 1650, by Simon, an ingenious English engraver, who first exhibited it in the crown and half-crown pieces of that period, but it had been practised before. The first piece yet known as an instance of it is a silver coin of Charles IX. of France, dated 1573; and the first medal is one of silver, of George Frederic, Marquis of Brandenburg, dated 1589. Briot, a French artist, gave the first specimen of it upon his Scottish coronation medal in 1633; and Simon, as we have just mentioned, introduced it into the larger coins at the

VOL. VIII.

period above stated. The means which he employed are not known; but in 1685 a very ingenious machine was invented for the purpose by M. Castaing; it was first introduced into the Mint in France, and afterwards into the English, and most of the other Mints of Europe. There is, perhaps, no one of the mechanical Arts which have undergone greater changes and improvements than that of coining; and, in order that the reader may the better comprehend and appreciate these changes, we shall give a description of the methods practised in the British Mint in the Tower, from its first establishment to the year 1811, when a new building was erected on Tower Hill, and an entire new process introduced.

Mechanical
Processes.

(874.) The first step, after properly assaying the metals, was that of melting and mixing them in a furnace; they were then cast into bars of proper length, and it appears that the casting was made in sand, as in other founderies; the bars were afterwards reduced by rolls as nearly as possible to their proper thickness, the gold bars having been heated again before they underwent the last process, but the silver plates and copper bars were passed through the rolls without heating.

Former
method of
coining by
hand-
presses.

The plates, whether gold, silver, or copper, being thus reduced as nearly as possible to the proper thickness, were cut into round pieces, or blanks, by a machine called a fly-press, as described under the article Button-making, the process being in fact exactly similar; but in coining, as greater accuracy is requisite in the result, so greater perfection is also necessary in the machinery. A few blanks were first cut, and examined as to weight, and, if they were generally too heavy, the bars were returned to the rolls, and these adjusted so as still further to reduce the thickness, and consequently the weight, of the blank; and if they were too light the bar was re-melted.

The proper thickness having been thus obtained, the process of cutting the blanks proceeded, and they were successively transferred to the proper officers to be adjusted, and brought, by filing the edges, to the weight of the standard whereby they were to be regulated. The remainder of the plate between the holes left by the blank was remelted again, under the denomination of *sizel*. The pieces were adjusted by a very fine balance; and those which proved too light were separated from the general mass, as were also any which were found too heavy, the former to be re-melted, and the latter to be adjusted to the proper weight. The extreme accuracy, however, of the present machinery in the Royal Mint has greatly reduced all this preliminary labour, although with the utmost attainable exactitude it is impossible to have the rollers so exact that there may not be a trifling difference in the thickness of the bar, and a difference of weight in the blanks, to dispense entirely with this examination in operating on the precious metals. The blanks, having been adjusted, were carried to the blanching house, where the gold blanks were brought to their proper colour, and the silver ones whitened, which operation was performed by heating them in a furnace, and, when cooled, boiling them successively in two copper vessels, with water, common salt, and tartar, and after that scouring them, and lastly washing them in cold water, drying them over a wood fire, in a copper sieve, in which they were put when taken out of the boiler.

The next operation was the milling on the edges; this, till lately, was performed by a machine, which, by the constitution of the Mint, was not shown to visitors,

4 K

Manufac-
tures.

although there is no doubt it was the same as that used in foreign Mints, where no secret is made of the process. It consisted of two plates of steel in the form of rulers, on which the edging is engraved, half on one side and half on the other. One of these plates is immovable, being strongly bound with screws to a copper plate, on a board or table; the other is movable, and slides on the copper plate by means of a handle, and a wheel or pinion of iron, the teeth of which engage in other teeth on the surface of the sliding plate. The planchet or blank, being placed horizontally between these two plates, is carried along by the action of the movable one; so that by the time it has made half a turn it is marked all round. This process is greatly improved in modern coining.

Stamping.

The next operation was that of stamping; this was effected by a machine consisting of a beam, screw, arbor, &c., contained within the body of it, except the first, which is a long iron bar, with a heavy ball of metal at each end, and rings, to which were fastened cords, to give it motion; in fact a fly-press in principle, but heavier, and differing somewhat in form from that described under (Art. 863.) The bar here was placed over the body of the machine; in the middle of the beam was fastened a screw, which, by turning the beam, served to press the arbor under it; to the lower end of the arbor, placed perpendicularly, was fastened the die or matrix of the reverse or arm side, in a kind of box or case, in which it was retained by screws, and under this was the box containing the die of the image side, firmly fixed to the lower part of the machine. When the blank was to be stamped it was laid by hand upon the lower die; two men then, pulling the rope attached to the fly-beam or lever of the press, forced down the upper die with great violence, and consequently the blank placed between them received at once, as at present, an impression on both sides, which completed the operation. Such is a general view of the former process of coining as it was carried on for many years, viz., from about 1662 to 1811, in the Tower of London; but in the latter years, as already stated, a new, elegant, and appropriate building having been erected on Tower Hill, and new machinery for the purpose placed therein by Messrs. Boulton and Watt, a new and improved process has been adopted from that time; although such has been the progress of mechanical invention since that period that several of these machines have been greatly improved by English engineers in the construction of some foreign Mints, the most recent of which is described in a subsequent page.

Origin of
the modern
machinery.

(875.) The origin of the new machinery dates a few years prior to the commencement of the present century, when Messrs. Boulton and Watt began to apply the power of the steam-engine at their manufactory at Soho to the operation of coining, and afterwards coined a large quantity of twopenny and penny pieces of copper, and halfpence and farthings, for Government, many of which are still in circulation. They also, a few years afterwards, recoined a considerable number of Spanish dollars for the Bank of England without first obliterating the former impression by rolling, or otherwise than by the restamping. They likewise constructed a complete coining apparatus for the Danish Government, and subsequently another for that of Russia.

This extraordinary effort of a private manufactory, and the circumstance of the new machinery being adopted by foreign nations, while our own Mint continued to proceed upon the old and imperfect method, was strongly

noticed by the late Lord Liverpool in a published letter to his Majesty George III., where his Lordship observes, "But the new machinery now employed in the manufactory of every sort of metal, in which the mechanics of this Country far surpass those of any other, has not in general been admitted into your Majesty's Mint. It is an acknowledged principle that machines that act with a given force can work with more truth and accuracy than the arm of man, the force of which necessarily varies occasionally, from several causes. Another practice has been invented, that of striking coins in a steel collar, so as to make them perfectly round, and all precisely of the same diameter, an improvement which certainly contributes to the beauty of the coin; new modes of putting what is called the graining on the edges of the coins have also been invented, which, at the same time that they protect the coins from being filed equally with the present mode, do not occasion those rough edges, which expose them to wear by abrasion or friction. For these, and many other valuable improvements, the public are indebted to the ingenuity of Mr. Boulton, of Soho, near Birmingham. It is singular that, though the manufactures of England have greatly profited by these inventions, the officers of your Majesty's Mint have never, or not sufficiently, availed themselves of them; the Mints in foreign Countries are in search of them, and their Governments, in more than one instance, have employed Mr. Boulton in erecting Mints on his new principle; and Parliament has authorized the same."—Earl of Liverpool, *Treatise on the Coins of the Realm*.

It was, probably, in consequence of these remarks, and the attention thus drawn to the subject, that orders were given for the new building and the new machinery; but, as above observed, such has been since the progress of mechanics in this Country, that even this new machinery, so justly admired when first constructed, is now itself comparatively old and imperfect with respect to other Mints since constructed for different foreign Powers by English engineers, of which latter Mr. Hague, of Cable-street, Ratcliffe, has made several, viz., for Holland, Prussia, Brazil, &c. We have been obligingly furnished by that gentleman with the description and drawings of a Mint he is at this time engaged in constructing, to be erected at Rio Janeiro, which is perhaps one of the most perfect pieces of machinery of the kind at present known. We propose, however, before entering upon a description of it, to present the reader with an account of the Royal Mint, with a survey of which we have been favoured.

(876.) *Description of the Royal Mint.*—The first business attended to in this Establishment is the assaying of the bullion, as it is received from the Bank of England, which takes place in the Essay Office of the Master of the Mint: it is here received into what is called the strong hold, and there kept till its fineness is ascertained, in order that its true value may be computed. This being determined, the parties concerned are requested to attend the office of receipt and delivery, to witness its weight, and to be informed of its fineness, and consequently of its value; a Mint bill is then made out, and given to the owner, by which he knows the exact value of his deposit.

The next step is the delivery of the bullion to the melting-house, which is furnished with all the requisite furnaces and apparatus, adapted not only to the melting of the gold and silver, but also with cranes for lifting it out of the furnace, mould, patterns, &c. But there is

Mechanical
Processes

Description
of the Royal
Mint.

Manufactures. nothing very particular in this part requiring minute description. It will be sufficient to observe that the furnaces in which the metal is melted are eight in number, and are arranged on opposite sides of the melting-house, in two rows of four each, a swinging crane being placed in the centre between four, which, by turning on its centre, comes over the centre of any one of the furnaces, and lifts a pot of melted metal, weighing about 400 pounds, from any one of the four, and by which it is conducted to the pouring machine.

This last named is an iron frame, in which is an iron hoop, turning on an axis on each side; into this hoop the melting-pot is received, and, by means of a screw, the hoop is made to embrace the pot tightly at the top, under its upper flanch; from the hoop descends a bar of iron; and to these again is connected, on the other side, an arch, on which teeth are cut; and in these a pinion plays, by means of which, and proper wheel-work, the pot may be inclined at any angle, and the metal thereby poured out in iron moulds, mounted in a frame, on wheels, by which they are successively advanced to receive the metal as the others are filled. The ingot moulds are of cast iron, each in two halves, having flat surfaces, to form the faces of the ingot; and rising edges, to form the sides, and another to form the bottom; whereby any number of them being placed contiguous, and confined together with screws in the frame, the same number, or rather the same number minus one, of moulds are formed; these all rest on the bottom of the carriage above described, to preserve them of the same height, but which may be adjusted at pleasure, to suit moulds of different sizes. The ingots, being thus formed, are transferred to the rolling-mill. The metal is melted in pots of cast iron. Commonly the silver is run into plates ten inches long, seven inches wide, and about half or five-eighths of an inch thick. The gold plates are ten inches long, four inches broad, and three-eighths thick. While the metal is pouring into the mould there are three portions taken from the top, the middle, and the bottom, and carried to the King's Essay Office, to be examined by the officer, to ascertain that the proper standard value is preserved.

Before quitting this part of the establishment we may observe that formerly, if not at present, in the process of melting there would necessarily be some waste; every thing, therefore, that can possibly contain any portion of the precious metals, such as the sweeping of the smelting-house, &c., is collected and carried to another apartment, in which are erected two grinding and two triturating mills, where the sweep is worked up, and the fine metals in part recovered, in the manner practised by refiners and goldsmiths.

The sweep thus brought together is ground into a powder, and passed through a fine sieve, by which the larger grains of metal are obtained. The sweep is then put, in small portions, into a wooden bowl, having two iron handles, by which it is carefully washed: the lighter particles, being absorbed by water, are collected in a large tub; the heavy, or metallic ones, are found deposited at the bottom of the bowl. By these means the most considerable of the particles of gold or silver are obtained. The powdered sweepings, however, which have been collected after the washing process, still contain portions of metal; to obtain these the sweep, in certain portions, is put into a mill, containing, generally, about one hundred weight of mercury, the remainder of the mill being filled with water; this is commonly called

the triturating mill; and each charge is agitated about four hours with an iron instrument, having four arms placed horizontally, in the shape of a cross, and fixed to the centre of the mill; and, for the better agitation of the sweep of the mercury, the motion of this mill can be reversed at pleasure.

The next process is the rolling; and the ingots, formed as above, are therefore transferred to the rolling-room, which is furnished with four pair of rolls, driven by a steam-engine of thirty-horse power. One pair of these rolls is shown in fig. 10, plate lvii. The two shafts are situated parallel to each other, and receive their motion from the engine. It is an excellent construction, executed by the late John Rennie, Esq.; but, except in the extreme accuracy and perfection of the workmanship, there is no difference between this and another rolling-mill; they therefore require no particular description.

Opposite to each pair of rollers is a furnace, into which the silver ingots are introduced, and heated to redness before being submitted to the rolls; they are then taken from the furnace, one at a time, and the rollers being adjusted to a proper distance, they are applied, with the longest side of the ingot to the rollers; this is caught again on the other side, in a pair of tongs, by another workman, passed over the top to the first, who again passes it to the other, and so on, the rollers being adjusted as the thickness is reduced, till, at length, what was at the beginning the length of the plate becomes its breadth, the rollers only stretching the metal in the direction of their motion; the plate, therefore, which was at first ten inches by seven, comes out about twenty-eight inches by ten, and consequently proportionally reduced in thickness. These first rollers, which work the metal hot, and serve to consolidate it, are called thereby breaking-down rollers. The plates, whilst still warm, are rubbed over with a weak solution of acid, to remove the colour produced by the heat; they are then cut up into narrow slips, according to the nature of the coin contemplated, by means of a pair of circular shears.

These are represented in fig. 11, plate lvii. The Circular machine is worked by a cog wheel at the extremity of the main shaft of the rolling-mill. It consists of a framing of iron A A, supporting two shafts B B, which are parallel to each other, and move together by means of two cog wheels C C. At the extremity of these two shafts are fixed circular cutters D E, overlapping each other a small quantity, as shown in fig. 12, where it is seen that each cutter has a rim of smaller diameter than the outside; this small rim of the upper cutter is behind it, at *e*, but is in front of the lower one, at *g*, so that the adjacent edges of the large rims, *f* and *k*, come in contact, and overlap each other a very little; by this means they act as a pair of shears, to cut any thing placed between them. The metal plate being therefore laid down against the straight edge or guide plate F, which is adjustable according to the required breadth, and the plate being once applied to the revolving cutters, they draw it forwards, dividing it into two strips, *c d*. Fig. 12 shows a section of the plate. The part *c* is conveyed from the top of the rim *k* of the lower cutter, and kept from rising by the small diameter *e* of the upper cutter; at the same time the upper part of the plate is depressed by the rim *f* of the upper cutter, and supported by the small rim *g* of the lower one. By this means the divided parts are prevented from coiling up into scrolls, as they would do without these precautions. The frame *l*, and screw *m*,

Mechanical Processes.

Rollers. Pl. lvii. Fig. 10.

shears. Fig. 11, 12.

Manufac-
tures.

serve for keeping the edges of the cutters in proper contact. The strips of metal being thus formed are taken to the other rollers, called burnishing rollers, where they are further reduced cold, and brought as nearly as possible to the proper thickness, being constantly applied to gauges to ascertain the progress of the reduction, the rollers being successively adjusted as the work proceeds.

Drawing
machine.

(877.) *Drawing machine.*—Notwithstanding all the care that can be bestowed at the rolling, some inaccuracy will be found in the thickness of different parts of the same metal plate, and, therefore, as a last process, each is now passed through a drawing machine, which was not a part of the original construction, but was afterwards added on the suggestion of Mr. Hague; it was, however, executed by Mr. Maudslay. It is a heavy cast-iron frame, standing three feet above the floor, and about twenty feet in length, with a well-planed upper surface, on which a carriage runs with great accuracy, the latter being furnished with jaws resembling those of a vice, which are made by means of screws to take a firm hold of the bar, which is reduced a little in thickness at the end, to pass it through the two fixed plates, through which it is to be drawn. These plates are fixed in a frame securely attached to the end of the long drawing frame above referred to, the plates themselves being adjustable by screws to the utmost degree of accuracy.

The carriage, furnished with two pair of wheels or rollers, moves on the two plane faces of the long frame, and in the opening between these is a long endless chain, which passes over rollers at each end of the frame: the chain passes above nearly on a level with the upper face of the machine, and returns below under the floor. The chain is double, each link resembling a clock chain, and the two are united by strong iron bars, at about a foot distance, their length being of course equal to the distance of the two chains, viz., about six inches. The steam-engine being put in motion gives rotation to the rollers, and these to the chain, which is not, however, in connection with the carriage till that connection is established by an apparatus attached to the latter, which turns on a joint on the carriage, and which is so balanced that, when free, the heavier part falls on the carriage itself. Suppose now a rod or plate of metal to have been passed through the plates and secured in the jaws of the drawing carriage, the apparatus above referred to is tilted down, and being furnished with a proper hook at the depressed end, this catches hold of one of the cross bars of the chain, and thus connects the latter with the carriage, and by the motion of the former the rod is drawn through the plates, and reduced to a uniform thickness, which could never be attained with revolving rollers. It should be observed that, the rod having passed through, the carriage has a tendency to start forward, and the apparatus we have mentioned, which is attached to the carriage, is relieved from its hold on the chain, and, being heaviest at the other end, it tilts up and is perfectly free, the two being thus disunited till another rod or plate is introduced, and the hook end again depressed by hand.

The plate being drawn through, there are in the same room several little hand-presses for cutting out a few trial blanks, which are taken to the Essay Office, and, if found too heavy, the plates are readjusted, and the rod drawn again till the proper thickness is obtained, and this, being determined in one case, is sure to be found so throughout, so that the tiresome and unscientific process

of adjusting the weight by the file is wholly, we believe, Mechanical dispensed with. It will, of course, be understood that Processes. this accuracy is not necessary in the copper coinage.

The thickness of the rods being thus adjusted, they are taken to the cutting-out house, in which are situated twelve cutting-out presses. They are arranged in a circle, with a strong iron vertical axle or shaft in the centre, carrying a heavy fly-wheel at its upper end; this is put in rotation by the steam-engine, and, being furnished with a coin, strikes the levers of the several presses in succession, and thereby cuts out the blanks, which fall into boxes beneath. The other end of the press lever is connected with a strong spring, which is charged or stretched by the same motion which depresses the cutter, and immediately the coin passes, this spring again raises the cutter, to be again in like manner depressed by the following coin, and so on, a boy gradually urging the plate forwards as the blanks are cut out. We shall not enter more particularly into a description of this machine, as we intend to describe a more recent one just completed for the mint of Rio Janeiro. The blanks in this state are taken to the annealing furnace, having been rendered too hard by the previous operations of rolling, drawing, &c., to receive the impression at the stamping-mill without this process.

The blanks being thus prepared are put into a sizing or milling machine, but this, like the old milling engine, is, by the constitution of the Mint, not shown to visitors, but we shall, in our subsequent description, explain that used at the mints constructed by Mr. Hague. It may be observed, however, that the sizing is only done to thicken, or what is called to upset the edge, in order to give a bold projecting edge to the coin, to protect the raised part of the impression. The milling on its edge being effected now at the same time the impression is raised by the coin being struck in a collar already milled.

It only now remains to describe the last process of stamping, the machinery for effecting which is by far the most elegant in the establishment. In this room four presses are ranged in a line along its centre, all resting on one solid stone basement. The nature of the press in its general operation differs in no other way from the common fly-press than in its motion from steam power, instead of by hand, as described in the old method, but there are several appendages to it which are very interesting. On the old principle the blanks were laid by hand, one by one, on the lower die, which necessarily rendered the operation slow, as great accuracy was required in placing them, and great danger to be apprehended if the press descended before the hand was removed. This evil is now very completely removed by what is termed a feeding apparatus, worked by the machine itself. A tube is placed in front of the machine, of exactly the diameter of the blanks to be coined, and into which two or three dozen blanks may be put, and others supplied occasionally by a boy, a few at a time, as the work proceeds—an operation entirely free from any danger; under the tube passes a slider, which is thrown backward and forward by an excentric on the shaft at every blow of the press: in the slide is a hole the exact size of the coin, and when, by the sliding motion, this comes under the tube, the lower blank in the same drops in, which is then urged forward by the slider on a base level with the top of the die till it is exactly over it, all which distances are accurately adjustable by proper screws, &c.: having placed it there, the slide is with-

Manufac-
tures.

drawn, but it is so contrived that the first effort to withdraw it opens the two parts which shut to form the circular hole, whereby the blank is left behind, and, as the slide returns, the parts which were opened again close and receive the next blank, which, as it advances, pushes away the last, which has now received its impression, and deposits another blank in its place.

We have said that every blank is struck in a collar; to effect this another appendage is requisite; but, as we shall explain this particularly in our description of the Rio Janeiro Mint, it will be sufficient to observe here, that, while the press is descending to make the impression, the collar rises from below to embrace the blank placed thereon, and after the impression is given, and during the ascending motion of the press, the collar is forced down again, leaving the stamped coin lying on the top of the die till pushed off by the feeding slider above described. By this means the milling on the edge is rendered very perfect, the rim of the coin is bold and projecting, and the utmost accuracy is attained in the size of the pieces. This completes the process, and we shall now proceed to describe rather more minutely than we have hitherto done the particular means employed to produce these effects according to the most recent and most perfect means.

Hague's
coining
apparatus.

(878.) *Coining apparatus by Mr. Hague.*—The complete apparatus, as supplied by the above ingenious mechanist, includes rolling-mills, drawing frame, cutting-out machine, milling machine, and stamping presses, but the two former differ so little from those which have been already mentioned that we shall confine our description altogether to those machines which are peculiar to coining, namely, the cutting-out machine, the milling or sizing machine, and the stamping presses.

Sizing
machine.
Pl. lvii.
Fig. 13, 14.

Sizing machine.—This is an extremely simple apparatus, exhibited in plan and section in fig. 13 and 14. A B is a substantial cast-iron frame, within which a wheel W revolves, leaving a certain and determinate distance between its circumference and a recess in the metal, the distance being of course alterable to the size of any proposed coin. The blanks are dropped in at the top, the wheel W being in motion, and are carried along with it in its motion, and reduced in their progress to the exact breadth intended, by which means their edges are thickened, and the bold and protecting rim of modern coins produced. At the bottom of the groove is a hole h, through which the blank passes to a drawer beneath.

Cutting-out
machine.
Pl. lviii.

Fig. 1 and 2, plate lviii. are the elevation and ground plan of one of the cutting-out machines, which are situated in a line parallel to each other, and are raised above the ground a sufficient height to permit the attendant to work in a convenient position. A A is a massive frame of cast iron, which is very firmly bedded upon masonry B B, and contains an interior screw, into which is accurately fitted a screw situated on the axle C C; but, in order to insure the perfectly vertical motion of the shaft, the part on which the screw is formed only extends for a short part on the middle of the shaft, and the upper and lower end are cylindrical, and turned perfectly true in a lathe; the opening for the shaft in the cast-iron framing is made considerably larger than the shaft, to leave room for its adjustment, which is effected by the screws a a a, situated at the upper and lower end, and thus any inaccuracies from wear, or any other cause, may be rectified, and a perfectly vertical motion of the shaft secured. The stamper and die do not differ from those commonly employed, except that the latter is si-

tuated within a cast-iron circular frame D D, furnished with screws for the purpose of adjustment.

Mechanical
Processes.

We have now to describe the manner of giving motion to the vertical shaft C C, which is the part where this machine differs most essentially from the common construction. E E is a hollow cast-iron pillar, firmly secured to the masonry by bolts d d, &c., in which a vacuum is continually kept by means of a pipe F, which communicates with an air-pump of the steam engine; G G is a cylinder having hollow axles, which vibrate in bearings in the hollow cast-iron frame H H, connected with the pillar E E, and thus, through the intervention of a pipe K, the air is exhausted in the cylinder when required, and a reciprocating motion given to the piston. The motion thus given to the piston is converted into a rotary motion by means of a crank attached to the vertical shaft L L, and this again, by means of a rod M M, communicates an alternating motion to the crank N in the arch of a circle, and consequently a vertical reciprocating motion to the shaft C C, the extent of which is varied according to the part of the crank to which the rod M M is attached. The cylinder G G is provided with flat pipes b b, which extend from each end to the hollow axle, and the axle is provided with apertures, so arranged with respect to that of the pipe K, that the cylinder is in connection with the vacuum during the descent of the piston, but, on its return, communicates with the atmosphere, so that the piston is free to return by the momentum of the fly-wheel P P. At the time it arrives at the top of the stroke the aperture of the hollow axle is again opposite the pipe K, so that the cylinder is in connection with the vacuum, and the piston again descends with the whole pressure of the atmosphere, and thus a rapid succession of blows is given by the stamper as the workman exposes a new part of the plate to its action.

In plate lix. fig. 1, is given an elevation of the coining machines, of which there are eight, situated at equal distances round a circular cast-iron vacuum chamber A A A. The framework of the machines B B, B B, &c., is of cast iron, and of the figure shown in the drawing, and each machine is secured to a solid mass of masonry which surrounds the vacuum chamber. The vertical shafts C C work in interior screws in the upper part of the framework, and are guided in their vertical motion by adjusting screws at the upper and lower extremity in the same manner as in the cutting-out machine. E E, &c., are drums situated on the vertical shafts, from which chains extend to the piston of the cylinders D D, &c., attached to the vacuum chamber, and serve, by the aid of the vacuum, to give motion to the stampers. To each vertical shaft is attached a fly-wheel F, which serves, by its momentum, to increase the blow given by the stamper, and at the same time too, by means of pins projecting from it, which strike levers connected with the valves G, effects a communication at the proper part of the stroke with the cylinders and the vacuum chamber; that is to say, during the descent of the piston the cylinder and chamber are connected with each other, but when it has arrived at the bottom of the stroke, the pin on the fly-wheel strikes the levers and changes the position of the valves, so that both top and bottom of the piston are in communication with the atmosphere, and the screw and stamper are free to return. When the piston arrives at the top of the stroke, another pin on the fly-wheel comes in contact with the levers, and throws them back into their original position, by which the cylinder is again put in communication with the chamber, and the

Coining
machine.
Pl. lix.
Fig. 1.

Manu-
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piston again returns with the full force of the atmosphere, and thus a constant succession of blows is kept upon each coin as it is introduced into the die.

There now remains to describe the manner in which the coin is introduced into the die before each blow is struck, and afterwards removed in order to give place to its neighbour:—*a* is a cast-iron box, situated on a level with the surface of the lower die, and *b* is a vertical lever which turns upon a bearing *c* attached to the frame, and receives a vibrating motion by means of an excentric *d* on the vertical axle *C*. To the bottom of this lever a flat horizontal arm extends into the box *a*, which contains an opening a little larger than the coin, and is of such a length that, when the lower end of the lever is in the position nearest the vertical shaft, the opening in the arm exactly coincides with the die; and when in the reverse position, *viz.*, when furthest from the centre of the machine, the opening corresponds with that of a tube *e*, in which the pieces of metal intended to be coined are situated. The bottom of the box is made inclined during a portion of the length, but is horizontal in the part situated nearest the die, which causes the horizontal lever, when it commences its return, to tilt up, and leave the coin which it has received in opening from the tube *e* in its proper situation in the lower die to receive the impression of the stamper. On its return it receives another piece of metal from the tube, which it conveys to the die, and pushes away the former piece of metal, which has been freed from the die by the following contrivance:—The lower die, which is formed on a cylinder the exact size of the coin, is surrounded by a collar which contains the impression to form the rim. This collar is attached by two levers, *ff*, to vertical rods *gg*, which are connected with a powerful spiral spring situated in the masonry below the machine, and to a cylinder *hh*, which forms a continuation of the vertical axle *C*, and has attached to it at the lower end the upper die or stamper. This cylinder works in a frame *kk*, which can be adjusted by screws, so that the upper and lower die exactly correspond with each other. When the shaft *C* descends by the force of the air cylinder it compresses the spiral spring, and at the same time raises the collar above the die a sufficient height to form a reception for the coin which has the instant before been left in its position by the lever above described; but the moment the blow is struck the vertical shaft is returned by its own reaction, assisted by the spring, which, in relapsing, forces the collar down, and leaves the coin free to be pushed off by the lever as it advances with a fresh piece of metal to be coined.

Clock and Watch-making.

Clock and
watch-
making.

(879.) Some means of measuring and subdividing time may be considered amongst the wants of civilized society, and it is accordingly found that methods and machines intended to accomplish this object are of very early origin. Of these instances are recorded in the Bible, such, for example, as sun-dials. We have, then, the clepsydra of the Egyptians and Greeks, the hour-glass, and other like approximative means. It was no doubt many years afterwards before the thought occurred of employing the natural force of gravity on a descending weight to effect the same object, and still later the introduction of the spring. The number of years which have passed even since the latter discovery have led to great perfection, and the extreme

accuracy which is now attained in the modern clock, which works on, day after day, for several days, and even weeks, without an error amounting to the fraction of a second per day, justly claims for this machine a very high rank as a work of Art; in fact it must be considered one of the most accurate and most perfect instruments due to human skill and ingenuity.

The term clock is generally applied to those time-pieces in which the motive power is a descending weight, and the regulating power a pendulum; and under this denomination we shall confine our description to such machines only; but, subsequently the watch, and other horological machines, will be illustrated and described.

The honour of the invention of the clock constructed according to the above definition, *viz.*, whose motive power was a weight, and regulated by some description of governor, is ascribed to different persons. According to some writers we are said to owe the discovery to Archimedes and Posidonius, while others ascribe the invention to Boethius, in the Vth Century; but this, from some remarks of the author, Hamberger supposes to have been a clepsydra, or water-clock, and not a clock moved by wheels and weights.

Invention
ascribed to
Boethius.

The machine sent as a present to Charlemagne by the King of Persia, in the year 807, is supposed by some to have been a clock like those used at present. This, however, like the former, Hamberger considers to have been nothing more than a water-clock, furnished with some ingenious mechanism, but having nothing in common with our clocks.

About the same period lived Pacificus, Archdeacon of Verona, who is celebrated for having invented a clock. His epitaph, besides relating other services which he performed, says,

Clock in-
vented by
Pacificus

*Horologium nocturnum nullus ante viderat,
Et invenit argumentum et primus fundaverat;
Horologioque carmen spheræ cæli optimum
Plura alia graviaque prudens invenit.*

Scipio Maffei considers that a clock moved by wheels and weights is here referred to. "This horologium," he remarks, "the like of which had been never seen, and which was different from a sun-dial because it showed the hours in the night-time, could not be a clepsydra or water-clock, for these were not only known to the Ancients, but even to the inhabitants of Italy, in earlier times; so that it could have been nothing but a clock like ours." It is argued, in reply to this, that, although water-clocks were known in Italy at that period, it is evident they were employed only by very few people, as stated in the writing of Cassiodorus on this subject. Moreover, that too much importance is attached to the words of the epitaph, *nullus ante viderat*, and that they might indicate but a slight difference in the construction.

Some ascribe the invention of our modern clocks to Gerbert, who in the Xth Century was raised to the Pontifical Chair at Rome, under the name of Silvester II., and who was reckoned to be the first mathematician and astronomer of his time. This, however, is only mere conjecture.

Invention
ascribed to
Gerbert in
the Xth
Century.

Among so great a variety of opinions and contradictions it is impossible to learn to whom we are indebted for the first idea of the modern system of clock-making. Hamberger states that there is no doubt clocks were in use in the Monasteries in Europe about the XIth Century; and that it is probable Europe is not entitled to the

Manufactures.

Clock by Wallingfort.

Clock by Henry de Wyck.

Description of De Wyck's clock. Pl. lx. Fig. 1, 2.

honour of the invention; but that it is rather to be ascribed to the Saracens, to whom we are indebted for many of the Mathematical Sciences.

The most ancient clock with wheels and balances mentioned in history, and of which the existence is positively known, was constructed in England by Richard Wallingfort, Abbot of Saint Alban, who lived in 1326.

Charles V., surnamed the Wise, King of France, caused, in the year 1370, a large clock to be placed in the tower of his palace by Henry de Wyck, whom he invited from Germany, because there was then at Paris no artist of that kind, and to whom he allowed a salary of six sols per day, with free lodging in the tower.

The precise construction of the clock of Wallingfort does not appear to have been handed down to us, but the description of the one last mentioned, by Henry de Wyck, is given at considerable length by Berthould, which, as forming not only a very interesting historical fact, but being serviceable in giving the reader an idea of clocks constructed on the modern principle, we translate from the author's own words.

(880.) In fig. 1 and 2 of plate lx. are given a front and side elevation of this machine. A is a weight suspended by a cord which is folded round a metallic barrel B, the axle of which has bearings in holes in the plates C C, D D. These plates were in the first clocks made of iron, and attached by being bent above and below at right angles, and which thus formed the frame.

The action of the weight A has a natural tendency to turn the cylinder B, and if it was not retained its descent would be by an accelerated motion; but this cylinder carries a catch wheel F, seen in fig. 1, the teeth of which engage the click c attached to the wheel C by a screw. The click is furnished with a spring, which, by exerting a pressure on the click, causes it always to engage the teeth of the wheel. This mechanism is for the purpose of winding up the clock. The action of the weight is in this way transmitted to the toothed wheel G, and from thence by a pinion e to a toothed wheel on the axle ff; this wheel again transmits the motion by a lantern pinion g to the wheel II, fixed on its arbor, which is called the crown or escapement wheel. This last wheel, by giving the pallets or short levers ik a motion alternately in opposite directions, produces a vibratory motion to the vertical arbor k, and, as the regulator or balance was fixed in this arbor, it was thus made to vibrate backwards and forwards at every push of the crown wheel upon the pallets. The pallets are placed upon the vertical arbor at an angle of about 90°, so that, when one of the teeth has passed the pallet, the other pallet presents itself to a tooth diametrically opposite, to be acted upon in its turn. This action of the crown wheel upon the pallets, which escaped the teeth alternately, was termed the escapement, or, by abbreviation, scapement of the clock; it is by means of it that the large weight is prevented from falling with rapidity to the ground by giving it a check, at every impulse of the wheel of escapement, on one or other of the two pallets; and the interval between two successive impulses being regulated by the time of a vibration of the balance, which could be adjusted by weights mm, fig. 2, placed at different distances on the arms L L of the balance, in notches made for the purpose, if the vibrations were too quick the momentum of the balance was increased by removing the suspended weights further from the centre of motion, and *vice versa*. As the balance was necessarily heavy to regulate a large maintaining power, the best

means of avoiding the friction became a consideration: Mechanical Processes. it was effected by suspending it by a cord, so that only part of its weight was borne by the lower pivot.

The clock was so contrived that the wheel G G made one revolution in an hour: the pivot b of this wheel extended outside of the plate, and had attached to it a pinion d, which engaged the wheel N N, and caused it to make one revolution in twelve hours; the axle of this wheel carried the index or hand O, which marked the hours on the dial.

The wheels and pinions have thus two offices to perform: the one to transmit the maintaining power in order to continue the motion of the balance; and, secondly, to indicate them in a visible form by a hand. To comprehend the manner in which this latter object was accomplished let us suppose the balance to be caused to make one vibration in the space of a second by the adjustment of the movable weights mm. By giving thirty teeth to the crown wheel I I it will make one revolution, while the balance makes sixty vibrations; for, at each revolution of the wheel, the same tooth acts once on the pallet h, and once on i, which produces two vibrations for each tooth, and thus, the wheel having thirty teeth, it is caused to make twice thirty vibrations; it therefore makes one revolution in a minute of time, and is required to make sixty revolutions during one of the wheel G. If the wheel G carries sixty-four teeth, and the pinion e eight, this pinion will make eight revolutions while the wheel has made one; and the wheel H having sixty, and the pinion g eight, it will give seven and a half revolutions to this pinion, on the wheel H, carried by the pinion e, makes eight turns for one of the wheel G; the pinion g therefore makes sixty revolutions during one of the wheel G; and, as we have seen that the wheel I I, carried by the pinion g, makes one revolution in a minute, it is evident the wheel G makes one revolution in an hour. On the same principle the pinion carried by the axle of the wheel G ought to make twelve revolutions while the wheel N N makes one, or have one-twelfth part the number of teeth on the circumference. While thus the train of wheels is transmitting the power of the suspended weight forwards to the balance, it is also counting the number of vibrations to constitute an hour which it points out on the dial-plate by a hand, a representation of which is given in fig. 3. A B are the plates of iron which are bent over at right angles at the top and bottom to form a framework for the wheels and pinions. The motive weight is suspended by a cord which is wound round the barrel G, which, like that employed in the clock, carries a click attached to the wheel H for the purpose of winding up the weight, the handle being placed on the square end of the axle of the pinion which engages the wheel I.

The wheel H carries twelve pins, b c, &c., which serve to elevate the hammer which strikes the bell: they are neither of them represented in the drawing, but it is easy to conceive an axle put in the frame which carries an arm which engages the pivot on the wheel H, and another to which is attached the hammer, and which, by this means, may be made to strike the bell.

The toothed wheel H engages the lantern d, fixed on the axle of the second wheel K, which also engages in the pinion e, the prolonged axle of which carries the fan L, which, by the resistance it experiences in the air, regulates the motion of the wheels, and the interval between each blow of the hammer.

The means by which the hammer is made to strike

Description of the striking part of De Wyck's clock. Fig. 3.

Manufac-
tures.

the correct number of blows in each hour were as follows:—The axle of the first wheel H was made to extend beyond the plate A, and carried a pinion of eight teeth, which engaged the wheel M, carrying seventy-eight teeth, so that this wheel made one revolution when the hammer had struck seventy-eight blows, or all the hours from one to twelve added together. On the axle of the wheel M was fixed another wheel, N, which had in the circumference twelve notches at unequal distances, varying in the proportion of the number of hours, 1, 2, 3, 4, &c. This last wheel regulated the number of blows which the hammer ought to strike at each hour. Over the circumference of the counting wheel N there was situated a detent *d*, having two claws, one of which reaches to the pins of the wheel N, and the other is situated within the frame directly over a single tooth *o*, on the axle of the fly L. Now, as the twelve-hour wheel revolves by the going part, one of its pins reaches the end of the long lever at every hour, depresses it, and at the same time raises the detent from the notch of the counting wheel, and also the short level V from its tooth *o*. The wheelwork, having nothing now to detain it, is immediately put in motion by the weight F, and continues to revolve until another notch of the count wheel arrives at the detent *a* which the detent falls into. The claw V again engages the tooth *o*, and the motion of the fly is stopped, and continues at rest until another hour elapses, when the detent is again raised from the twelve-hour wheel, and the striking machinery again put in motion, the same operation being repeated at every hour of the day, the number of blows of the hammer depending on the interval between the notches on the count wheel, which, as before stated, are arranged in the ratio of the number of hours, so that, the lever of the clock being so adjusted that twelve blows will be given while passing the largest interval, the number of blows struck at each succeeding hour will be correctly indicated.

This ingenious clock machinery, although, of course, much improved since this period, exhibits certainly a great effort of skill, considering the state of mechanics at the Age in which it was invented. About the year 1370 Strasburg had a clock, a description of which is given by Couland Dasypodius.

Clock at
Strasburg
in 1370.

Courtray
clock.

Courtray was about the same period also celebrated for its clock.

Clocks ap-
plied to as-
tronomical
purposes.

(881.) Public clocks were, soon after this period, erected in several of the principal cities of Europe, and in the year 1484 they had attained a sufficient degree of perfection to be useful for astronomical purposes, to which they were applied by Walther at Nuremburg.

Springs
used as a
motive
power.

About the commencement of the XVIth Century the spiral spring was first used as a prime mover, and the clocks were so much reduced in size as to become applicable to private houses; it is said that they were even made sufficiently small to be rendered portable, or, in fact, made in the shape of watches: it is not, however, probable that so great a change would be made at once, but that the reduction in size was gradually brought about, as the successive attempts were not found sensibly to affect the accuracy of the clock.

Fusee in-
vented.

(882.) When the spring was used as a first mover it was soon found that its power at the commencement of its action was much greater than towards the completion, and that an irregularity in the rate of the machine was in consequence produced. This naturally led to the invention of the fusee, which consists of a kind of cone upon which the chain from the spring is wound up, so that in

relapsing itself its force is exerted at a lever equal to the radius of the cone at the part at which the chain was situated. Thus, by reducing the diameter of the cone in an inverse ratio to the relaxing power of the spring, an equal degree of motive force was at all times exerted upon the machinery of the timekeeper.

Mechanical
Processes.

A clock upon this principle was some time ago in the possession of Mr. Pickett, of No. 50, Old Compton Street, which, from an inscription engraven in the Bohemian language, appears to have been made in the year 1525, by Jacob Leck, of Prague. It contained a spiral spring with a fusee of soft metal, and a screw at the end of the double levers of the balance for adjustment, instead of the movable weights we have described as being employed in De Wyck's clock. It had also some wheelwork to show the motions of the sun and moon in an engraven ecliptic, and also a contrivance to strike one at every hour. A catgut was originally the band of the fusee, and a modern metallic chain has been substituted, which has unfortunately destroyed nearly three out of the eight spiral threads at the smaller end; so that, instead of going forty-eight hours, (its former time,) the remaining five threads will only allow it to go thirty, which it now does, although irregularly, the vibrations being nearly one second each.

Beckmann, in his *History of Inventions*, mentions this clock as having been the property of Mr. Ferguson, at whose sale the present proprietor purchased it in the year 1777.

It appears probable that this construction of clock was not that first employed with the spiral spring, but that the unequal action of the latter was regulated by an additional spring, which, being disposed in a particular curve, opposed the principal spring when first wound up, and acted in the same direction with it as the intensity began to relax.

(883.) We have now to relate a most important event in the history of clock-making, viz., the discovery of the isochronal property of the pendulum by Galileo, which discovery may be fairly said to have laid the foundation of the modern system of clockwork, where, in availing ourselves of this property, a nearer approach to true time can be accomplished, even with rough work, than could be attained previously to this invention by the most accurate workmanship.

Isochronal
property of
the pendu-
lum dis-
covered by
Galileo.

The honour of the discovery of the properties of the pendulum is, without dispute, attributed to Galileo; but not so with its first application to clockwork, this being a subject of great contention; and it is to be regretted that, owing to the prejudiced opinions of most writers in favour of their own Countrymen, and the desire of attributing to them the honour of the discovery, the facts connected with it are so completely misrepresented that it is impossible to arrive at the truth with any degree of certainty.

Application
of the pen-
dulum to
clocks.

We are informed by Professor Venturi, *Essai sur les Ouvrages Physico-Mathématiques de Leonard de Vinci*, that Sanctorius applied a pendulum to clockwork some time before the year 1625. Vincentio Galileo, the son of the famous Galileo, is also said, *Exper. de l'Acad. del Cimento*, to have made a pendulum clock, suggested by his father's discovery, so early as the year 1649, at Venice; but Christian Huygens, the justly celebrated mathematician and philosopher of Zuylichem, contested the honour of the priority with him, which gave rise to the excellent Treatise on clockwork, *De Horologio Oscillatorio*, which laid the foundation of

First appli-
cation of
the pendu-
lum dis-
puted by
Galileo and
Huygens.

Manufac-
tures.

most of the subsequent improvements in horometrical machines, and in which it appears indubitably that he made, or directed the making, of a pendulum clock before the year 1658. From comparing what has been deduced by these two contending mathematicians, an impartial reader is led to conclude that Vincentio Galileo may have applied the pendulum in a rough, mechanical manner; but that Huygens's experiments were conducted more scientifically and perfectly; and probably without the knowledge of what his opponent had previously done: hence the honour of the invention has been generally attributed to Huygens.

He discovered that the isochronal property ascribed to the pendulum was only true in circular arcs of the same degree of vibration, and that a long arc required somewhat more time for a vibration than a short one, so that variations in the maintaining power produced variations in the time indicated, by altering the length of the arc of vibration of the pendulum. This inequality is so small as to be insensible in one vibration, and thus it was not detected by Galileo; but when the pendulum was employed to measure days, months, and years, the inequalities accumulated and seriously affected the accuracy of the clock. Huygens sought by the aid of Geometry the curve in which a body would descend in equal times in whatever part of the curve the oscillation commenced, and found it to be the cycloid, so that if the pendulum could be made to vibrate in the curve of a cycloid, the vibrations would be perfectly isochronal.

This discovery was very beautiful and important in a theoretical point of view, but its practical application, as a method to cause a pendulum to move in such a curve, was a matter of considerable difficulty. Huygens proposed the following ingenious method, which may be thus explained:—Suppose a thread is unwound by raising the extremity from a curve of any figure which it is caused to envelope, this extremity will describe another curve differing in properties from the first. Huygens found a curve was required from which, if a thread was unwound, the extremity would describe a cycloid. By this contrivance, which does high honour to the ingenuity as well as the science of Huygens, he caused the bob of the pendulum to vibrate in a true cycloid, but it has not been found of practical utility. Indeed, although the discovery of this law has been of infinite use in the Sciences of Astronomy and Geography, yet it has not in any degree been rendered practically useful in the construction of clocks until lately, by Mr. Frodsham, any further than that, by the knowledge of the irregularity of the vibrations in long and short arcs, the same length of the arc is preserved as much as possible, which, in stationary clocks, can be very nearly arrived at, as the only cause for the length of the arc diminishing is the decrease of the maintaining power by any additional friction of the machine.

(884.) The pendulum, although so admirable a regulator for stationary clocks, was of course totally inapplicable to those intended to be portable, and the vibrating balance, which was liable to considerable error, still continued to be the only means of governing them. Soon after this period, however, Hooke and Huygens introduced a slender spring to quicken and regulate sluggish vibrations of the balance, which has ultimately turned out to be of eminent utility. It is disputed which of these two skilful mechanics first introduced this pendulous spring. Berthould asserts, that although Hooke applied it first in a straight form, yet Huygens first adopted the

spiral shape as being most favourable to isochronism, while others are of opinion, certainly with more probability, that Hooke actually applied it in a spiral form among the twenty different methods which he stated in his Lectures at Gresham College, in the year 1664, might be used to answer the same purpose. (*Lectiones Cutlerianæ*, 1673.) Indeed, the account of the spiral springs adopted by Huygens was not published in the *Philosophical Transactions* until the year 1675, No. 112, whereas Hooke had discovered the isochronism of springs, and registered its discovery, in the year 1658.

The instruments for measuring time from this period assumed two distinct forms, viz., those governed by a pendulum, which were called clocks, and which were stationary, and those governed by the balance, termed watches, chronometers, or portable timekeepers, which, from the construction, might be transported from one place to another without materially affecting their rate of going.

As the common clocks and those for portable purposes were now totally different, both in the principle of regulation as well as in their construction, it will be proper, in pursuing the account of the progress of the improvement in these machines, to treat of them separately; and we therefore now continue the history of the pendulum clocks till we arrive at its present state, and shall then again resume that of watches, from the above period of the history to the present time.

(885.) *Construction of the common clock.*—To enable the reader to comprehend the successive inventions which have added to the perfection of clocks, it is necessary, first, to describe the common clock movements, and the manner in which the pendulum is made to act as a regulator, which, once properly understood, the nature and action of the improved means which have been introduced to increase the dominion of the pendulum will be readily comprehended. In fig. 4, plate lx., is a side elevation of a common clock without the striking machinery, which have been omitted in this figure to prevent the confusion. A A, A A are two brass plates, connected together by pillars B B, which together form a frame to afford bearing for the various axles of the machinery. The maintaining power of the clock is a weight W, which is suspended to a line, one end of which is attached to the wooden support of the clock C C, and the other passes over a pulley and is wound upon the barrel *a a*, by means of a handle which fits on the square end *c* of the axle projected through the face F F of the clock. The force exerted by the weight, of course, gives motion to the barrel, and from thence, by the toothed wheel and a pinion, to the axle *e e* of the minute hand; and, by the further intervention of the wheels and pinions, *f, g, h, i*, to the axle *j* of the second hand. To this axle the regulating power of the pendulum is applied in the following manner:

Immediately over the axle of the second hand is situated another axle *k*, having a bearing at one end in the cheek of the framework, and at the other in a projecting piece attached to the other cheek. This axle is provided with a vertical rod I, of the shape shown in the figure, having an opening in the horizontal part *m* to admit the rod of the pendulum. The pendulum consists of a weight made of a shape to expose as little resistance to the air as possible, (usually termed a *bob*,) which is attached to a vertical rod, the upper part of which terminates in and is attached to a piece of metal *o*. To the same piece of metal is attached, immediately above it, a

Mechanical
Processes.

Construc-
tion of the
common
clock.

Pl. lx.
Fig. 4.

Spring
added to
the balance.

Manufac-
tures.

slender spring *n*, terminated by a square piece of metal *p*. The upper part of the spring is introduced in a slit in the projected piece on the cheek, and made in a line with the axle of the seconds hand, and the square piece of metal, above described, resting on the sides of the slit in the pendulum, is of course suspended by the spring *n*, and free to vibrate; but the part *o* being through the opening in the branch *m* of the vertical rod *m*, the oscillation given to the pendulum is communicated to the axle *k*, situated above that of the seconds hand. Upon the axle of the seconds hand is fixed a toothed or ratchet wheel *q*, and immediately above, on the axle *k*, is a claw, termed the escapement wheel, which embraces the upper part of the wheel and allows one tooth to pass at each vibration of the pendulum. The tendency to motion of the wheel *q*, communicated from the maintaining power, exerts a pressure upon the escapement as it approaches the extent of oscillation, which permits it to escape, and, although small the pressure from the increase of velocity above that of the maintaining power, is sufficient to continue the vibration of the pendulum, which would of course otherwise in time subside. Thus this beautiful contrivance, while it receives motion from the clock, regulates its velocity, as long as the length remains unaltered, with a degree of surprising accuracy.

In order that the seconds hand may perform one revolution in a minute, the ratchet wheel *q* is made with thirty teeth, and the pinions *f*, *g*, *h*, *i* are so arranged, that one revolution of the axle *e* is made during sixty of that of the seconds hand, by means of which the minute hand will complete one revolution in an hour. The hour hand, which has to perform a revolution in twelve hours, or to move at one-twelfth the speed of the minute hand, is attached to a hollow cylinder or tube which fits upon the axle of the minute hand. To this cylinder is fixed a toothed wheel *s*, the action of which is seen in the figure: this engages a pinion *t*, revolving upon a pin or axle fixed in the cheek of the framework, which is put in motion by two equal toothed wheels, *u* and *v*, the former of which is situated on the axle of the minute hand, and the number of teeth in this wheel and pinion *s* and *t* being made in the ratio of one to twelve, the hour hand is caused to perform its revolution in the time required. The wheel *u* is not fixed upon the axle of the minute hand, in order that the hands may be set without affecting the works; motion being conveyed to it from the axle of the minute hand by means of a slender spring, which, by pressing against the wheel with a certain degree of force, causes it to revolve, and at the same time will permit the wheel *u* to be turned upon the axle without in any way straining the machinery when it is required to alter or set the hour hand. The minute hand is in a similar way permitted to turn without affecting the machinery, by making the part of its axle a hollow cone, and fitting the part to which the hand is attached within, by which a sufficient friction is obtained on the surfaces of the cones to continue the motion, at the same time the minute hand can be moved to any part of the dial without doing any injury.

(886.) *Striking part.*—Having thus described all the works of the clock whose office is that of measuring the time, we proceed next to the machinery for the purpose of striking the hours, which, although performing a less important office than the former, is composed of a greater number of parts, and is more complicated in its arrangement. This is represented in the plate in the separate fig. 5 and 6.

Striking
part.

Pl. lx.
Fig. 5, 6.

Fig. 5 is a side elevation, and fig. 6 a front elevation, with the front plate removed, the wheels being represented by single lines, which the writer considers will render the several bars and levers more distinct and more readily comprehended. *A A A A* are the cheeks of the framework to support the axles of the wheels and pinions, and *a a* the barrel to which the weight is suspended to give motion to the machinery, wound up by a square projecting part of the axle in the same manner as has been described in the clockwork. The motion of the barrel is communicated, by a system of wheels and pinions *b*, *c*, *d*, to the axle *e*, upon which is situated a fly or fan *f*, which revolves with great rapidity, and which, by the motion of the barrel being greatly multiplied by the arrangement of the wheels and pinions, acts as a governor to the motion of the machinery.

The striking machinery remains at rest until the termination of each hour, when it is put in motion by the works of the clock, and continues in motion until it has struck the number of hours indicated by the hour hand on the dial, when it again stops and remains quiescent until the next hour again puts the machinery in motion. This is effected in the following manner:—*g* is a horizontal axle extending across, and having bearings in the cheek *A A*; it has attached to it in the part extending beyond the cheek a lever *h*, shown dotted in fig. 6, which rests upon a pin fixed in the wheel *v* put in motion by the clockwork. As this wheel, as before described, is equal to the wheel *u* upon the axle of the minute hand, it of course completes one revolution in an exact hour. At the end of each hour, therefore, this lever is raised, and with it the lever *i* situated within the frame, also attached to the same axle. This lever is situated immediately under another lever *j*, attached to an axle *k*, which it raises with it, and at the same time two other levers *l*, *m*, one of which rests in a notch wheel *n n* attached to the barrel, and the other in a notch in a rim attached to the toothed wheel *c*; by this means the only preventive to the motion of the wheelwork is removed, and the action of the machinery commences: *o o* is another axle, situated parallel to the two former ones, *k* and *g*, with a lever which rests upon pins fitted into the toothed wheel *b*, seen in fig. 5. As the motion of this wheel continues, it causes the head of the hammer *H*, which is situated on a rod attached to the same axle, to recede from the bell. On the same axle is also situated a stud or short lever, which, as the receding motion of the hammer takes place, presses against a spring *s* attached to the cheek, and thus when the motion of the wheel *b* has continued sufficiently to relieve the lever from the pin, the hammer is returned with considerable force and strikes the bell *B*. The lever *l*, before described, is at this time resting by its weight upon the circumference of the wheel *n n*, which is provided with notches at distances varying in the ratio of the number of hours, one, two, three, four, &c., up to twelve. As long as the lever rests upon the circumference of this wheel no impediment is given to the motion of the machinery, but immediately it arrives at a notch it falls by its weight, the lever *m* falls into the notch in the wheel *c*, and the motion is stopped. It will thus be seen that the wheel being divided into notches at proper distances, and the fly made of such a size that the twelve blows is given while passing the longest interval, the number of hours denoted by the clock may always be announced by the striking machinery.

(887.) *Compensation pendulums.*—Soon after the

Mechanical
Processes.

Manufactures.

Compensation pendulums.

application of the pendulum to clocks, it was found that the expansion and contraction of the bar or rod materially affected the rate of going. M. Lalande found the alteration in the length of a bar of iron, forming a second pendulum, to amount to nearly 0.178 of an English inch for 30° of Reaumur's thermometer; so that being regulated in the summer, the clock would gain in winter twenty seconds a day. It became, therefore, important to astronomers to have the pendulum rod composed in such a way as to correct the expansion and contraction of the metals, and various methods have been suggested to accomplish this object.

Mercurial pendulum.

(888.) *Mercurial pendulum*.—The first pendulum which was applied to a clock on this principle was the mercurial pendulum invented by Graham, which consisted of a steel rod, the lower end of which carried a large glass jar filled with mercury, so that the expansion or contraction of the rod might be counteracted by the opposite expansion and contraction of the mercury. The construction of this instrument is represented in fig. 1 of plate lxi. where *a a* is the rod of the pendulum which is of steel, and it is formed into a frame *b* at the lower end termed the stirrup, to receive the jar of mercury *c*, which at the same time that it counteracts the effects of the downward expansion of the rod serves as the weight or bob of the pendulum. The adjustment for time is made by the piece of metal *d* which slides upon the vertical rod, and by its position determines that of the centre of oscillation of the whole pendulum, and the adjustment for compensation is made by adding to or subtracting from the mercury in the jar, which alters the relative lengths of the columns of the two metals.

Pl. lxi.
Fig. 1.

The whole length of a pendulum of this construction is about 44 inches, the expansion and contraction of which is corrected by a column of mercury of 7.5 inches in the jar. The diameter of the jar is about 2 inches, and the weight of mercury from ten to twelve pounds, which, including that of the stirrup frame and rod, makes the total weight about fourteen pounds.

The advantages which mercury presents as the means of compensation have led to many attempts at improvements in the construction of the pendulum. One evil resulting from the construction employed by Graham is, that the correction for compensation, by the addition or subtraction of mercury from the jar, causes a change of place with the index point on the graduated arc.

Reid's mercurial pendulum.
Fig. 2.

This evil Mr. Reid proposes to correct by the following construction, of which a drawing is given in fig. 2, where *A B* is the pendulum rod, *C C*, *D D*, the stirrup or frame, within which is situated a frame *E E* provided at the bottom with a horizontal plate termed the *soles*, on which the jar containing the mercury is situated, and which is provided with a cover *F*. *G* is the regulating or adjusting screw, for the purpose of correcting the rate of the clock, and *H* is the index which serves to show, by a graduated plate fixed to the inside of the clock-case, the number of degrees to which the pendulum oscillates.

If the steel rod *A B* and rods of the jar frame are lengthened by heat, the jar containing the mercury will also be lowered, and the centre of oscillation carried further from the point of suspension; but the heat which lengthens the rod will at the same time expand the mercury upwards in a greater degree, and by this means the centre of oscillation is always kept at the same distance from the point of suspension. When the rods are contracted or shortened by cold, the mercury will also be

contracted by it, and hence the lengthening or shortening of the pendulum rod by heat or cold is compensated by opposite expansions and contractions of the mercury.

(889.) *Parkinson and Frodsham's mercurial pendulum*.—The improvement we are here about to describe, although applied to the mercurial pendulum, is not necessarily confined to that apparatus only, but is a fundamental principle applicable to any pendulum whatever. Mr. Frodsham, the partner of the firm Parkinson and Frodsham, No. 1, Change-alley, well known for the many excellent chronometers they have supplied to navigators, having considered all the circumstances which attend the vibration of pendulums generally, was led to an investigation of the effect which the length and strength of the spring, by which the pendulum is supported, had upon the length of the arc of vibration, the time of oscillation, and the duration of the time the pendulum would continue to vibrate when the maintaining power was not applied. This is a point which does not appear to have been before attended to; yet when we look to the laws of pendulums, it will at once appear that it must have an influential effect. In determining the centre of oscillation, we in fact assume that those particles of the body which are nearest the point of suspension tend, by their momentum, to accelerate the motion of other particles more remote; while those near the extremity in like manner retard the motion of the particles intermediate between the extremity and the axis of suspension; but in order that these two forces may have the influence we attribute to them, it is essential that the line or rod by which they are connected should be inflexible; consequently, if a rigid bar be attached by a flexible line to a point of suspension, and be put in vibration, the motion of the system will not be the same as we contemplate in our investigation; for the particles nearest to the point of junction of the flexible and rigid line cannot have the same effect upon the more distant particles as they would have if the whole were rigid; and in like manner the more distant particles cannot affect those near the point of junction according to the laws depending upon absolute rigidity; and the consequence is that, beside the actual vibration of the whole system upon the point of suspension, the rigid part of the pendulum has an oscillatory motion about some point within itself. The action of gravity, therefore, instead of being wholly engaged during the descent in accumulating power to urge the pendulum through the ascending arc, is partly employed in correcting the position of the rod, and, consequently, *a priori*, we ought to expect that a pendulum thus supported and started to vibrate in any given arc will arrive more quickly at a state of rest than another of the same length in which this defect has not place. Now if this must necessarily happen when the pendulum is supported by a flexible line, it must also in part happen when the line is replaced by a very weak, flexible spring, which scarcely differs in its effect from the line itself; but the defect will become less and less as the strength of the spring is increased, till at length the strength of the spring is too great for the weight of the pendulum, when a diminution of the arc and time of vibration will again occur from this new cause. It seems, therefore, that a certain strength of spring is better adapted than any other in any given case for prolonging the whole time of the pendulum's motion, and that this is the proper degree of strength to employ when the maintaining power is used, because a less effect will in this case

Mechanical Processes.

Parkinson and Frodsham's mercurial pendulum Fig. 3.

Manufactures.

one required to perpetuate the oscillations. Another point is no less theoretically true, that although the arc of vibration of a pendulum, when turning on infinitely fine knife edges, is a part of a circle, it can be so no longer when suspended by a spring; and it is by no means unlikely that a certain length and strength of spring may tend much more than another to approximate the arc of vibration to that of a cycloid, and hence permit all arcs of vibration to be performed in equal times.

Fig. 3.

It was these and certain practical observations which led Mr. Frodsham to enter upon a very interesting course of experiments, and to invent a mode of suspension which, while the length of the pendulum is preserved, will allow him to select that length of spring best suited to his purpose. This contrivance is represented in fig. 3. Here it will be seen that the tube *c d*, sliding stiffly on the rod *a b*, the latter being attached to the spring, if the tube be slipped upwards or downwards, and the slip at its upper part made to embrace the spring, the length of the latter may be varied at pleasure while the whole pendulum will preserve its length unaltered. Mr. Frodsham in a letter to the author, speaking of the means of determining the best length of spring, observes, that it appeared at first a difficult undertaking; but, being determined to go through the investigation, he selected a number of suspension springs, all precisely of the same length, but each differing from the other in strength, and also a silken thread; and first suspending the pendulum by this thread, the moving power not being on, and carefully raising the bob 2° , he then left it to vibrate by its own gravity; noting the time when the arc was reduced to 1° and to $\frac{1}{2}^{\circ}$, and the whole time before it came to rest. This was repeated three times.

The next experiment was with the weakest spring, the time noted as before, and repeated also three times. In like manner the several springs were tried in succession, each gradually increasing the whole time of vibration, till at length he had the satisfaction of finding amongst them that which enabled the pendulum to preserve its state of vibration for several hours; whereas the same pendulum suspended by the silken string or weak spring came to rest in little more than an hour.

Frodsham's mercurial pendulum differs also in some other respects from the usual pendulum, where commonly the vessel of quicksilver is supported by a stirrup as we have described, and is rather difficult to be managed and adjusted by a person not conversant with clockwork. Instead of this, Mr. Frodsham has a hole in the bottom of the glass vessel, in which is fitted an iron tube; the end of this is received in a counter sink in the cover, which has also a hole in it; the suspension rod is a cylinder of steel which passes through the hole above mentioned, and the vessel is supported by a nut which screws on to the bottom of the rod, while another nut on the rod itself may be run down to press upon the cover, and thus keep every thing firm; the glass vessel is likewise elliptical instead of cylindrical, and, vibrating edgewise, is supposed to offer less resistance. The adjustment of the pendulum is, from what has been stated, very simple; to lengthen it, it is only necessary to run down the lower nut, and then again to run down the upper nut to reach the top of the glass vessel; and to shorten it, the upper nut must first be run upwards to enable the lower nut to raise the vessel. The first clock made on this principle was ordered by Mr. Barlow of

Woolwich, for the College of Virginia in America, agreeable to the wishes of the late venerable President Jefferson, who just lived to see it in its place. For the above particulars the author has been indebted to Mr. Frodsham, only such verbal alterations being made as were necessary to render it a part of the general article.

(890.) *Gridiron pendulum*.—This is composed of nine round rods, five of which are made of steel and four of brass, somewhat resembling the common gridiron, and from which it probably derived its name. A drawing of this pendulum is given in fig. 4, where the brass rods are distinguished by having a slight shade over them. These rods are adjusted in such a manner, and made of such lengths, that, notwithstanding the unequal contraction of the two metals, a motion is given to the centre of gravity in a contrary direction to that which it would have had from the use of a single rod. By making use of this form, Harrison, after a great number of experiments, composed a pendulum, of which the centre of oscillation always remained at the same distance from the point of suspension, notwithstanding the variations of heat and cold in the course of the year.

The construction of this pendulum will be readily understood from the drawing given in the figure. The outside bars *a b*, *a b*, are of steel, and are attached to the cross pieces *A B* by pins, and form the exterior frame; to the lower bar *B* is attached the bars of brass *c c*, *d d*, parallel to the former, the upper ends of which are fixed in the same manner to a cross piece *c*, made free to move between the bars *a b*, *a b*. To this piece is also attached the third pair of bars *e f*, *e f*, which are of steel, and the lower end of which terminates in a fourth cross piece *D*. This in its turn carries a fourth pair of bars of brass *g h*, *g h*, which terminate above in the fifth transverse piece *E*, to which is attached the steel rod carrying the weight or bob of the pendulum; the adjustment for the rate of the clock being effected by a screw at the lower part.

It will be seen that by this arrangement, as the expansion of the steel lowers the centre of oscillation, that of the brass has a tendency to elevate it, and thus the length of rods of the different metals being made inversely as their powers of expansibility, the distance of the centre of oscillation from the point of suspension will remain constant. The principle upon which the gridiron pendulum acts is of course the same as that of the mercurial pendulum before described, viz., that the expansion of the rod is counteracted by that of a metal having a greater expansive power acting in an opposite direction. In the former case, the correcting metal employed being of great expansive power, the height of the column is required to be but small, while in the latter, the correcting metal having an expansibility not greatly exceeding that of steel, the brass rods are required to extend a great portion of the length of the pendulum.

Although, in theory, five bars only are necessary for constructing a gridiron pendulum, nine are found requisite in practice, in order that the bar to which the pendulum is immediately suspended be equally supported on each side, to prevent the tremulous motion and bending of the bars which would otherwise take place.

(891.) *Ellicot's pendulum*.—The next pendulum of any importance it is necessary to speak of is that of Mr. Ellicot, the description of which we give nearly in his own words. It is represented in fig. 5, in which *a b*

Mechanical Processes.

Fig. 4.

Fig. 5.

Manufac-
tures.

is a bar of brass, made quite fast at the upper end by pins, and held contiguous to the rod of the pendulum which is of iron, at several equal distances, by the screws *s s*. The pendulum rod as far as the brass extends is made of the same figure; but a little below the end of the brass bar, the iron is left broader for the convenience of fixing the work to it, and is made of sufficient length to pass through the ball of the pendulum C. The holes in the brass through which the screws pass into the iron rod are made of sufficient length to permit the brass to contract and dilate freely by heat and cold under the heads of the screws: *ff* represent two strong pieces of steel or levers, whose inner centres or pivots turn in two holes drilled in the broad part of the pendulum rod, and their outer ones in a strong ridge screwed upon the same part of the rod, but omitted in the drawing, in order to exhibit the internal mechanism; *g g* are two screws entering at the edge, and working in the cavity near the centre of the ball. The ends of the screws next the rod are made of the figure shown in the drawing, which pressing with the weight of the ball against the lower arms of the levers cause the short ends to press against the brass bars at *b*. The parts being adjusted in this situation, let us suppose the rod of the pendulum and brass rod annexed to it to be elongated by heat. As the brass lengthens in a greater degree by the heat, it will force the short ends of the levers downwards, and at the same time necessarily lift up the ball, which rests on the long ends of the same levers at *ff*, to any proportion necessary, and, provided the ends of the screws press upon the levers at a proper distance from the centres or pivots, the ball will be always kept at the same distance from the point of suspension, notwithstanding any alteration the rod of the pendulum may be liable to from heat or cold. What this distance ought to be may be determined, if the difference of expansion between the brass and iron is known, for the proportion the shorter arms of the levers ought to bear to the longer ones will always be as the excess of expansion of the brass to the whole expansion of the iron.

Ellicot's
pendulum
improved
by Cum-
mings.

The correctness of the principle of this instrument, although so obvious as scarcely to require demonstration, is founded upon the supposition that the pendulum rod is perfectly inflexible, and that all the parts move without friction, in which case the operation must be perfectly smooth and uniform; but as Mr. Cummings remarks, in his excellent Treatise on Clockwork, if the pendulum rod be in any degree flexible, or friction take place in any part, which of course must always be the case in practice, the operation must be attended with a degree of irregularity of motion, which, although imperceptible to the sight, must affect the accuracy of the instrument. To remedy these evils, Mr. Cummings proposed that three bars should be made use of, one of brass and two of steel, firmly connected at one end, and held together by any determinate power towards the other; here the steel bar being situated on each side of the brass, endeavour by means of the limited power which connects them to bend it, each operating in its own way, so that they counteract and destroy each other's defects.

Pl. lxi.
Fig. 6, 7, 8.

This construction will be understood by inspecting fig. 6, 7, 8 of the plate, where fig. 6 is a front view of the bars connected together, fig. 7 a side elevation of the same, and fig. 8 a front elevation of the brass bars separate. The bars *s s*, as they move on the surface of

the intermediate bar, by the different contraction and expansion of the metals, press upon the piece of metal C in such a manner that each should have equal action notwithstanding the inaccuracies of execution, and a greater degree of regularity produced than could be attained by the two rods alone. Ellicot's pendulum, constructed in this manner, Cummings conceived to equal in many respects the gridiron pendulum, with the advantage of being more easily and accurately adjusted.

Mechanical
Processes.

(892.) *Smeaton's pendulum*.—The pendulums above described are those whose application to astronomical clocks has been most extensive; but a great number of inventions have been made to effect the same object, which, although differing in the materials and construction, the principle upon which the adjustment is effected is similar in all cases. The pendulum we are now about to describe consisted of a glass rod about half an inch in diameter and 45.5 inches long. To the upper end is fixed the pendulum spring, and to the lower a screw and regulating nut. A brass ring or tube of about an inch in length is placed so as to move easily on the lower end of the rod, having a fillet at each end, one of which being in the regulating nut, and the other supports several tubes of zinc, iron, and lead, which compose what may be called the pendulum ball. The inner cylinder, which is of zinc, is $12\frac{1}{8}$ inches in length, one-eighth of an inch thick, and made to fit easily on the glass rod, the lower end resting on the upper fillet of the brass ring. On the zinc cylinder is another of iron 12 inches long and $1\frac{1}{8}$ of an inch thick, made easily movable on the zinc tube, and with a kind of bottom to it, in which is a hole for the glass rod to go freely through. The upper end of this tube rests on a fillet on the upper end of the zinc tube, and the lower end has a fillet on its outside, on which rests a leaden tube of 12 inches long and one-quarter of an inch thick, which goes easily over the iron tube.

The action of this pendulum will thus be readily understood; the rod being made of glass, the expansion by heat is small, and is counteracted by the opposite and superior expansion of the metal cylinders, which can be adjusted of such a length that the centre of oscillation does not alter its distance from the point of suspension.

(893.) *Troughton's tubular pendulum*.—This celebrated artist, to whom Science is so much indebted for the great perfection of astronomical instruments, has turned his attention to this subject with considerable success, and has produced a pendulum very perfect in its action.

Trough-
ton's tubu-
lar pendu-
lum.

A representation of the instrument is given in fig. 15, which with the following description in the words of Mr. Troughton will enable the reader to form a clear idea of its construction and action. The rod A B is composed of a tube of brass, reaching from the bob nearly to the spring, which contains another tube within, in which are five wires so disposed as to produce together (like the wire bar gridiron of Harrison) three expansions of steel downwards and two of brass upwards, whose lengths being inversely proportional to their dilatation, destroy the whole effect that either metal would have singly. The small visible part of the rod near the top is a brass tube, whose use is to cover the upper end of the middle wire, which is here single and otherwise unsupported.

Commencing from the top, the first action is downwards and consists of the pendulum spring, a short wire 0.2 inches diameter, and a long wire 0.1, which are all of steel and firmly connected together; they reach within an inch of the centre of the hole and occupy the

Manufac-
tures.

middle line of the whole apparatus. To the lower end of the middle branch is fastened the lower end of the interior brass tube, 0.6 in diameter, which terminates a little short of the top of the exterior tube, and produces the first dilatation upwards. From the top of the interior tube are suspended ten wires, 0.1 in diameter, whose situation is in a line at right angles to the swing of the pendulum, and reach somewhat lower than the attached tube itself, which they pass through without touching, and effect the second expansion downwards. The second action upwards is effected by the exterior tube, whose internal diameter is sufficient to allow the interior tube to pass freely through it; its bottom is connected with the lower ends of the last-described wires. To complete the connection, a second pair of wires, of the same diameter as the former, and occupying a position at right angles to them, acts downwards, reaching a little below the exterior tube, having also passed through the interior one, but without touching either. The lower ends of these wires are fastened to a short cylindrical piece of brass, of the same diameter as the exterior tube to which the bob is suspended by its centre.

Fig. 9 is a section of the rod, where the three concentric circles represent the tubes, and the rectangular position of the two pair of wires round the middle one is shown by the five small circles.

Fig. 10 explains the part which closes the upper end of the interior tube; the two small circles are the two wires which are suspended from it, and the three large circles show the holes through which the middle and other pair of wires pass.

Fig. 11 is intended to represent the part which stops up the bottom of the interior tube; the small circle in the centre is the part where the middle wire is fastened to it; the others, the holes for the other four wires to pass through.

Fig. 12 is the part which closes the upper end of the external tube; the large circle in the centre is the place where the brass covering the upper part of the middle wire is inserted, and the two circles denote the fastening for the wires of the last expansion.

Fig. 13 represents the bottom of the exterior tube, in which the small circles show the fastening places for the wires of the second expansion, and the larger ones the holes for the other pair of wires to pass through.

Fig. 14 is a cylindrical piece of brass, which shows how the lower end of the wires of the last expansion are fastened to it, and the hole in the middle is that whereby it is pinned to the centre of the bob. The fastenings of the upper ends of the two pair of wires are done by screwing them into the pieces which stop up the ends of the tubes; but at the lower end they are all fixed as represented in the figure.

In the apparatus thus connected, the middle wire will be stretched by the weight of the whole, the interior tube will support at its top the whole, except the middle wire, the second pair of wires will be stretched by all, except the middle wire and interior tube, the exterior tube supports at its top the weight of the second pair of wires and the bob, and the second pair of wires is stretched by the weight of the bob only.

This pendulum is one which, from the simplicity of the arrangement, possesses considerable advantages over many of these inventions; it however possesses the disadvantage of any change of temperature not acting upon all its parts equally, or being felt by the exterior

tubes before its action can arrive at the wires in the interior, which will of course for a time affect the position of the centre of oscillation.

(894.) *Thomas Reid's pendulums.*—We are indebted to Mr. Thomas Reid of Edinburgh, the author of a late Work on clock and watch work, for many suggestions of improvements in the various parts of clock machinery, and among others the subject of pendulums has engaged his attention. One of these which he has employed in the construction of clocks consists of a zinc tube and three steel rods, the manner of arranging and fastening of which will be sufficiently well understood by the drawing, fig. 16. The action is as follows: the centre steel rod when lengthened by heat will descend with the zinc tube; but the same cause which lengthens the rod *ab* downwards will expand the zinc tube upwards, and this will carry up the two outside steel rods by which the ball of the pendulum is suspended; their expansion downwards, as well as that of the centre rod, is compensated by the upward expansion of the zinc tube. The length of the rods and of the zinc tube must of course be in proportion to the expansive ratios of the metals.

Mr. Reid has also proposed a pendulum, of which the materials employed are glass and zinc. It is composed of two tubes, the interior being of glass, and 54 inches in length; upon the exterior of this is a zinc tube of 16 inches in length, which rests on iron at the bottom of the glass tube, and supports at the upper end the ball of the pendulum. As the glass tube is expanded it will carry down with it the zinc tube; but as this will be expanded in a greater ratio, the ball of the pendulum situated at the top will retain the same distance from the point of suspension, and a perfect compensation effected.

This instrument is very simple, and probably equally effective in its motion with the last described; but its liability to fracture, attending a glass tube of great length and small diameter, will always be against its use.

(895.) *Mr. Adam Reid's pendulum.*—This differs very little from the preceding, except that the material employed in the interior rod was steel instead of glass, as proposed by Mr. Thomas Reid; but the exterior cylinder, to which the bob was attached, was zinc in both cases. The construction of the pendulum is represented in fig. 17. *AB* is the steel rod extending through the whole length, *C* the bob, supported upon the compensating cylinder of zinc *D*, which surrounds the rod *AB*, and rests upon a nut *E* of a screw tapped upon the end of the steel rod to bring it to exact time; as this expands downwards by heat, the zinc expands upwards the same quantity, so that the ball always remains at the same distance from the point of suspension.

On Wooden Pendulums.

(896.) The small degree of the expansion and contraction of the fibres of wood in the direction of their length has led to the use of this substance for the rods of pendulums, and although they are in some degree affected by temperature and by the moisture of the atmosphere, the rate of clocks constructed in this manner approaches very nearly to those with a metallic compensation pendulum. The justly celebrated Colonel Beaufoy has made a very interesting series of experiments on clocks furnished with wooden pendulums, which are given in

Mechanical
Processes.

Thomas
Reid's zinc
pendulum.

Fig. 16.

Thomas
Reid's
glass pen-
dulum.

Mr. Adam
Reid's pen-
dulum.

Fig. 17.

Wooden
pendulums.

Manufactures.

Thomson's *Annals of Philosophy*. He first fitted up a clock beating dead seconds, and whose motion continued while winding up, with a straight grained cylindrical deal rod, which he was on the point of rejecting from the irregularity of the rate, when it occurred to him, from the circumstance of the clock becoming much out of beat, that the great error probably proceeded

from the warping of the wood. He therefore caused the intermediate portion of the deal, from about an inch below the part where the pendulum spring is fastened to the upper part of the bob, to be reduced from a cylindrical to an elliptical shape, the transverse or longest diameter being parallel to the back of the clock, and by this means very much improved the going.

Mechanical Processes

Table containing the Rate of a Clock with a Wooden Pendulum.

Date.	Clock fast or slow.	Differences.	Daily rate.	Date.	Clock fast or slow.	Differences.	Daily rate.
1819.				1819.			
Jan. 31	- 0' 10.40"	—"	—"	Aug. 3	- 1' 55.09"	1.29"	- 0.43"
Feb. 6	- 0 02.07	8.33	- 1.39	7	- 1 58.41	3.32	- 0.83
10	- 0 03.37	5.44	- 1.36	10	- 2 10.05	2.64	- 0.88
13	- 0 07.91	4.54	- 1.51	14	- 2 03.39	2.34	- 0.59
20	- 0 18.55	10.64	- 1.52	21	- 2 07.80	4.41	- 0.63
25	- 0 23.47	4.92	- 0.98	*25	- 0 10.88	3.08	- 0.77
March 4	- 0 30.45	6.98	- 0.99	26	- 0 09.75	1.13	+ 1.43
9	- 0 38.00	7.55	- 1.51	27	- 0 09.53	0.22	+ 0.91
14	- 0 46.00	8.00	- 1.60	28	- 0 09.83	0.30	- 0.30
18	- 0 50.17	4.17	- 1.04	31	- 0 07.14	2.69	+ 0.89
22	- 0 50.67	0.50	- 0.13	Sept. 2	- 0 07.95	0.81	- 0.40
24	- 0 50.25	0.42	+ 0.21	6	- 0 06.34	1.61	+ 0.40
26	- 0 50.32	0.07	- 0.03	9	- 0 08.55	2.21	- 0.74
29	- 0 50.10	0.22	- 0.07	13	- 0 08.84	0.29	- 0.07
April 1	- 0 52.02	1.92	- 0.64	17	- 0 11.67	2.83	- 0.71
3	- 0 23.86	1.84	- 0.92	19	- 0 10.33	1.84	+ 0.67
5	- 0 54.20	0.34	- 0.17	21	- 0 10.75	0.42	- 0.21
7	- 0 54.34	0.14	- 0.07	23	- 0 08.55	2.20	+ 1.10
10	- 0 55.05	0.71	- 0.24	Oct. 1	- 0 20.05	11.50	- 1.44
15	- 0 57.22	2.17	- 0.43	4	- 0 18.01	2.04	+ 0.68
27	- 1 08.06	10.84	- 0.90	9	- 0 18.25	0.24	- 0.05
29	- 1 08.73	0.67	- 0.34	12	- 0 21.38	3.13	- 1.04
May 1	- 1 08.61	0.12	+ 0.04	14	- 0 23.57	2.19	- 1.09
4	- 1 06.07	2.54	+ 0.85	16	- 0 24.03	0.46	- 0.23
7	- 1 04.37	1.70	+ 0.57	18	- 0 24.10	0.07	- 0.04
9	- 1 03.77	0.60	+ 0.30	22	- 0 21.90	2.20	+ 0.55
12	- 1 01.40	2.37	+ 0.79	27	- 0 18.58	3.32	+ 0.66
14	- 1 01.70	0.30	- 0.15	Nov. 3	- 0 16.60	1.98	+ 0.28
17	- 1 00.15	1.55	+ 0.52	6	- 0 17.22	0.62	- 0.21
22	- 1 58.70	1.45	+ 0.29	10	- 0 16.50	0.72	+ 0.18
28	- 1 01.64	2.94	- 0.49	12	- 0 15.66	0.84	+ 0.42
June 5	- 1 00.81	0.83	+ 0.10	21	- 0 15.56	0.10	+ 0.01
7	- 1 02.00	1.19	- 0.59	23	- 0 13.53	2.03	+ 1.02
9	- 1 02.85	0.85	- 0.42	†26	+ 1 02.58		
16	- 1 04.98	2.13	- 0.30	Dec. 3	+ 0 59.20	3.38	- 0.48
19	- 1 07.96	2.98	- 0.99	8	+ 0 57.58	1.62	- 0.32
21	- 1 10.62	2.66	- 1.33	11	+ 0 57.08	0.50	- 0.17
30	- 1 19.32	8.70	- 0.97	13	+ 0 57.87	0.79	+ 0.49
July 3	- 1 22.70	3.38	- 1.13	22	+ 0 47.60	10.27	- 1.14
7	- 1 29.72	7.02	- 1.75	24	+ 0 47.16	0.44	- 0.22
17	- 1 43.54	13.82	- 1.38	27	+ 0 47.47	0.31	+ 0.10
19	- 1 45.50	1.96	- 0.98	30	+ 0 48.07	0.60	+ 0.20
22	- 1 50.68	5.18	- 1.73	31	+ 0 48.74	0.67	+ 0.67
23	- 1 50.91	0.23	- 0.23	1820.			
25	- 1 53.05	2.14	- 1.07	Jan. 3	+ 0 49.11	0.37	+ 0.12
26	- 1 54.44	1.39	- 1.39	5	+ 0 48.45	0.66	- 0.33
28	- 1 54.38	0.06	+ 0.03	8	+ 0 49.16	0.71	+ 0.24
29	- 1 54.90	0.52	- 0.52	15	+ 0 48.84	0.32	- 0.05
31	- 1 56.38	1.48	- 0.74	22	+ 0 45.94	2.90	- 0.41
				31	+ 0 37.72	8.22	- 0.96

* Aug. 24, clock put forward two minutes.

† Nov. 25, clock taken to pieces and cleaned.

Manufac-
tures.

Colonel Beaufoy has given the continuation of his observations on the rate of this clock, which will be found in vol. i. and iii. of the *Annals of Philosophy*, which are equally satisfactory in their results, and confirmed his good opinion of the advantages in the use of this kind of pendulum. The success of this first

experiment induced him to try the effect of wood of greater density, and for this purpose he selected a straight grained piece of teak, which he applied to a clock, and registered the rate in the same manner as with the former pendulum, as given in the following Table.

Mechanical
Processes.

Date.	Clock fast or slow.	Differences.	Daily rate.	Date.	Clock fast or slow.	Differences.	Daily rate.
1824.				1824.			
April 1	+ 0' 01.40"	—"	—"	Dec. 1	— 0' 26.82"	2.70"	— 1.35"
7	+ 0 03.00	1.60	+ 0.27	3	— 0 28.87	2.05	— 1.02
10	+ 0 03.90	0.90	+ 0.30	8	— 0 33.41	4.54	— 0.91
27	+ 0 16.00	12.10	+ 0.71	10	— 0 35.80	2.39	— 1.20
29	+ 0 17.43	1.43	+ 0.71	12	— 0 38.13	2.33	— 1.16
May 1	+ 0 18.36	0.93	+ 0.46	16	— 0 48.20	10.07	— 2.52
6	+ 0 23.15	4.79	+ 0.96	20	— 0 56.54	8.34	— 2.08
10	+ 0 24.07	0.92	+ 0.23	26	— 1 06.86	10.32	— 1.72
19	+ 0 34.75	10.68	+ 1.18	29	— 1 07.68	0.82	— 0.28
21	+ 0 37.06	2.31	+ 1.16	1825.			
26	+ 0 43.18	6.12	+ 1.22	Jan. 1	— 1 08.53	0.85	— 0.28
31	+ 0 45.21	2.03	+ 0.41	6	— 1 09.60	1.07	— 0.21
June 1	+ 0 45.51	0.30	+ 0.31	8	— 1 08.14	1.46	+ 0.73
4	+ 0 47.55	2.00	+ 0.67	13	— 1 04.28	3.26	+ 0.65
7	+ 0 49.65	2.10	+ 0.70	17	— 0 59.56	5.32	+ 1.33
9	+ 0 49.75	0.10	+ 0.05	19	— 0 56.56	3.00	+ 1.50
12	+ 0 51.16	1.41	+ 0.47	26	— 0 46.25	10.31	+ 1.47
18	+ 0 59.88	8.72	+ 1.45	29	— 0 38.95	7.30	+ 2.43
22	+ 1 02.75	2.87	+ 0.72	Feb. 2	— 0 34.30	4.65	+ 1.16
28	+ 1 06.00	3.25	+ 0.55	4	— 0 30.89	3.41	+ 1.70
July 2	+ 1 05.73	0.27	— 0.07	8	— 0 23.10	7.79	+ 1.95
4	+ 1 03.89	1.84	— 0.92	12	— 0 17.04	6.16	+ 1.54
9	+ 0 58.04	5.85	— 1.17	21	— 0 03.85	12.19	+ 1.46
13	+ 0 57.94	0.10	— 0.02	March 4	+ 0 18.68	22.53	+ 1.88
17	+ 0 53.43	4.51	— 1.13	8	+ 0 27.65	8.97	+ 2.24
19	+ 0 51.60	1.83	— 0.92	12	+ 0 33.44	5.76	+ 1.45
21	+ 0 50.97	0.63	— 0.32	14	+ 0 35.31	1.84	+ 0.94
23	+ 0 51.31	0.34	+ 0.17	18	+ 0 42.99	7.68	+ 1.92
27	+ 0 52.77	1.46	+ 0.37	21	+ 0 48.76	5.77	+ 1.92
Aug. 3	+ 0 53.40	0.67	+ 0.09	24	+ 0 54.61	5.85	+ 1.95
9	+ 1 09.44	16.04	+ 2.67	31	+ 1 11.83	17.22	+ 2.46
17	+ 1 04.91	4.53	— 0.57	April 2	+ 1 18.34	6.51	+ 3.25
21	+ 1 05.15	0.24	+ 0.06	4	+ 1 23.38	5.04	+ 2.52
24	+ 1 04.16	0.99	— 0.33	8	+ 1 37.30	13.62	+ 3.40
27	+ 1 07.35	3.19	+ 1.06	12	+ 1 52.47	15.47	+ 3.87
Sept. 1	+ 0 56.00	3.35	— 2.67	18	+ 2 21.63	29.16	+ 4.86
6	+ 0 50.28	3.72	— 0.76	21	+ 2 38.24	16.61	+ 5.54
9	+ 0 58.65	1.37	+ 0.46	28	+ 3 14.26	36.02	+ 5.15
13	+ 0 53.13	1.48	+ 0.37	30	+ 3 23.08	8.22	+ 4.41
16	+ 0 50.60	2.58	— 0.84	May 2	+ 3 31.60	8.52	+ 4.26
18	+ 0 48.33	2.27	— 1.13	4	+ 3 39.46	7.86	+ 3.93
22	+ 0 42.53	5.80	— 1.45	7	+ 3 49.26	9.80	+ 3.27
25	+ 0 38.24	4.29	— 1.43	10	+ 3 58.27	9.10	+ 3.00
28	+ 0 36.42	1.82	— 0.61	14	+ 4 11.67	13.40	+ 3.35
Oct. 4	+ 0 32.58	3.84	— 0.64	17	+ 4 22.53	10.86	+ 3.62
9	+ 0 26.88	5.70	— 1.14	22	+ 4 40.43	17.90	+ 3.98
14	+ 0 22.37	4.51	— 0.90	25	+ 4 51.15	10.72	+ 3.57
18	+ 0 21.80	0.57	— 0.14	28	+ 5 63.94	12.79	+ 4.26
24	+ 0 14.76	7.04	— 1.17	30	+ 5 14.72	10.78	+ 5.39
30	+ 0 08.68	6.08	— 1.01	June 6	+ 5 44.46	29.74	+ 4.25
Nov. 3	+ 0 04.53	4.15	— 1.05	15	+ 6 12.50	28.04	+ 3.12
6	+ 0 03.43	1.10	— 0.37	18	+ 6 26.85	14.35	+ 4.78
15	— 0 05.92	9.35	— 1.04	20	+ 6 38.63	11.78	+ 5.89
21	— 0 16.20	10.28	— 1.71	23	+ 6 56.94	18.31	+ 6.10
24	— 0 19.72	3.52	— 1.17	25	+ 7 09.49	12.55	+ 6.27
29	— 0 24.13	4.41	— 0.88	30	+ 7 40.99	31.50	+ 6.26

Manufactures.

TABLE continued.

Mechanical Processes.

Date.	Clock fast or slow.	Differences.	Daily rate.	Date.	Clock fast or slow.	Differences.	Daily rate.
1825.				1825.			
July 2	+ 7' 53.43"	12.44"	+ 6.22"	Sept. 1	+ 3' 52.56"	7.49"	+ 3.75"
5	+ 8 08.67	15.24	+ 5.08	3	+ 3 58.50	5.96	+ 2.98
10	+ 8 35.81	27.14	+ 5.43	7	+ 4 16.63	18.13	+ 4.56
13	+ 8 48.13	12.32	+ 4.11	12	+ 4 39.32	22.69	+ 4.54
15	+ 8 55.72	7.59	+ 3.79	20	+ 5 02.15	22.83	+ 2.83
17	+ 9 03.79	8.07	+ 4.03	26	+ 5 10.00	7.85	+ 1.31
20	+ 9 19.76	15.97	+ 5.32	29	+ 5 13.50	3.50	+ 1.17
23	+ 9 43.90	24.14	+ 8.05	Oct. 1	+ 5 17.94	4.44	+ 2.22
25	+ 10 01.82	17.92	+ 8.97	8	+ 5 25.25	7.31	+ 1.04
27	+ 10 20.57	18.75	+ 9.37	12	+ 5 27.83	2.58	+ 0.64
*30	+ 10 46.85	26.28	+ 8.76	16	+ 5 30.51	2.68	+ 0.67
Aug. 1	+ 0 16.97			21	+ 5 39.46	8.95	+ 1.79
6	+ 1 04.50	47.53	+ 9.50	27	+ 5 52.60	13.14	+ 2.19
14	+ 2 15.70	71.20	+ 8.90	31	+ 5 59.23	6.63	+ 1.66
20	+ 2 56.19	40.49	+ 6.75	Nov. 6	+ 6 10.21	10.98	+ 1.83
23	+ 3 13.00	16.81	+ 5.60	12	+ 6 25.89	15.68	+ 2.65
26	+ 3 27.40	14.40	+ 4.80	19	+ 6 44.97	19.08	+ 2.73
30	+ 3 45.05	17.65	+ 4.91	23	+ 6 53.46	18.49	+ 2.12

* July 30th stopped the clock.

Col. Beaufoy's remarks.

Colonel Beaufoy remarks that, "by comparing this Table with the former, it appears that the pendulum, with a rod of heavy wood, is, in point of accuracy, inferior to the one made of light wood; the greatest daily variation of the latter being from minus 2.74" to plus 1.48", sum 4.52"; while with the other it varied from minus 2.52" to plus 9.5", sum 12.02". Colonel Beaufoy died a short time after this period, or it was his intention to have pursued these experiments with different woods, and to have thus added to the valuable store of experimental facts which have distinguished the life of this worthy and excellent man.

Ludham's pendulums.

Wooden pendulums of rather different construction have been made use of in the *Astronomical Observations*, published at Cambridge by the late Rev. William Ludham, Professor of Mathematics in that University; he has described a very neat and ingenious mode of fitting up a pendulum with a wooden rod, constructed for the purpose of preventing any gyratory motion. It was effected by having the pendulum ball of an equal mass round the centre of a round wooden rod, and by a thin flat hard steel crutch to give impulse on the hardened ends of two screws put through the rod, which screws retained the flat crutch as nearly as possible in the plane or line of the diameter of the pendulum rod, or at right angles to the middle plane of the pendulum ball. The ball was nearly of the form of a cheese, or the middle frustum of a globe. For a more particular account, see Ludham's *Observations*, page 81.

It must, however, be admitted that, although the wooden pendulum, from its simplicity and cheapness, is highly deserving of attention, it cannot be put in competition with a corrected metallic pendulum; not only from being defective in complete compensation, but from the lateral contraction and expansion of the wood from heat and moisture which causes a liability of the joints becoming loose, an evil which, although in some measure remedied by the use of varnish, has always a certain influence in pendulums of this construction.

The use of marble, talc, and other substances, for the rods of pendulums, has been attempted, but as the

experiments do not appear to have been attended with success, or, at all events, the pendulums constructed of these materials have not been brought into general use, we do not conceive it necessary to enter into any description of them, but refer the reader to the list of Works on this subject given at the end of the article.

On Clock Escapements.

(897.) The escapement is that part of the machinery of the clock by which, at each vibration of the pendulum, one tooth of the escapement wheel is permitted to pass, and is of course the means by which the pendulum influences the regularity of the clock. As the motion of the pendulum is preserved by the maintaining power, its vibrations must be, in some measure, influenced by the degree of force which it exerts; and consequently any difference in the action produced by increased friction of the axles from the congelation of the oil, from cold, or other causes, must affect, in some measure, the rate of the clock. It therefore became a great desideratum to obtain an escapement, such that the time of the vibrations of the pendulum would not be affected by any variation in the maintaining power; and a great number of inventions have been proposed to attain this object, the most important of which we now propose to lay before the reader.

In the escapement first employed, which is similar to that represented in the clock by Henry de Wyck, the teeth of the escapement wheel press against pallets situated upon an axis alternately in opposite directions, and as the pressure is continually aiding the pendulum in its vibration, any alteration in that pressure, produced by a variation of the motive force, will evidently affect the time of vibration and the rate of the clock.

(898.) The anchor escapement, which is that employed in the present day, was invented about the middle of the XVIIth Century, but the inventor does not seem to be known with certainty, although there is great reason for supposing that we are indebted to Dr. Hooke for this valuable discovery in addition to the many others

Manufac-
tures.Pl. lxii.
Fig. 1.

which he made in the Art of Horology. This contrivance is as follows: on the axis A (plate lxii. fig. 1) of the pendulum, or balance, is fixed a piece of metal, E A F, called the *crutch* by our artists, and *anchor* by the French, shown in the position which it takes when the pendulum is at rest. It terminates in two faces, B b, C c, of tempered steel, or of some hard stone, termed the *pallets*, upon which the teeth of the wheel act. These faces are made at such an angle that the teeth push them out on each side; thus B pushes the pallet to the left, and C pushes its pallet to the right. To comprehend the action, suppose the pendulum to be drawn aside to the right at Q, and then let go; it is plain that the tooth B pressing on the face of the pallet m B b all the way from m to b thrusts it aside outwards, and thus, by the connection of the crutch with the pendulum rod, aids the pendulum's motion along an arc parallel to Q P R. When the pendulum reaches R, the point of the tooth B has reached the angle b of the pallet and escapes from it. The wheel pressing forward, another tooth C drops on the pallet face C c, and by pressing this pallet outward evidently aids the pendulum in its motion from R to P; the tooth C escapes from this pallet at the angle c, and now a tooth B' drops on the first pallet and again aids the pendulum, and this operation is repeated continually.

It will be remarked that each tooth of the wheel acts on each pallet in succession, and that, during its action on either of them, the pendulum marks one vibration. The number of vibrations, therefore, during one turn of the wheel is double the number of teeth; consequently while the tooth slides along one of the pallets, it advances half the space between the two successive teeth, and when it escapes, the other tooth is just in contact with the other pallet. Should this second tooth chance to touch the pallet before the first has escaped, the wheel will advance no further, and the motion of the pendulum will be gradually stopped. For these reasons it is usual to allow one tooth to escape a little before the other reaches the pallet, and to allow a small drop of the teeth from pallet to pallet; it is, however, accounted bad workmanship to let the drop be considerable.

The pendulum is made to swing somewhat beyond the angle of escapement, for if it does not do so when the clock is clean and in good order, but stops precisely at the drop of the tooth, when it grows foul and the vibration diminishes, the teeth will not escape at all, and the clock will immediately stop.

This circumstance of exceeding the angle has also great influence on the performance of the clock, as it greatly affects the governing power of the pendulum. It is easy to see that when the face m b of the leading pallet is a plane, if the pendulum continue its motion to the right from P to Q after the tooth B has dropped on it, the pallet will push the wheel back again, while the tooth slides outwards on the pallet m. Such pallets will therefore make a recoiling escapement, resembling in this circumstance the old pallet employed with the crown wheel, one consequence of which is that it is not affected by any inequalities of the maintaining power.

According to a series of experiments made by Berthould, a clock, with a half seconds' pendulum weighing five drachms, was furnished with a recoiling escapement whose pallets were planes. The angle of escapement was five and a half degrees; when actuated with a weight of two pounds, it swung 8° and lost $15''$ per hour; with four pounds it swung 10° and lost $6''$. Thus it appears that by doubling the maintaining power, although the

vibration was increased in consequence of the greater impulse, the time was lessened $9''$ per hour, or about $\frac{1}{400}$. Although the variation in the maintaining power will never be to this extent, yet in so many wheels and pinions and axles, the power to effect the motion is so considerable that the variation produced by friction from cold would be sufficient to destroy the accuracy of a clock constructed with such an escapement.

(899.) Graham's escapement, called the dead beat escapement, from the circumstance of the seconds' index standing still after each drop, is represented in fig. 2. The acting face of the pallet a c is a plane, the tooth drops on a and escapes from c, in the middle point between the two when the pendulum is perpendicular. Beyond a the face of the pallet is an arch, the centre of which is the centre of the crutch. The maintaining power is so great as to produce a vibration of the pendulum greatly exceeding the angle of the escapement: the consequence of which is that when the tooth drops on the angle a the motion of the crutch is continued, the tooth presses upon the surface of the arch, but without producing any effort to accelerate the pendulum, and with no other retardation than that due to the friction of the surfaces.

It will thus be seen that, in this escapement, the pendulum gets its impulse in the very middle of its vibration where its velocity is the greatest, and the maintaining power only acting upon it for a short time, it will make but a trifling alteration in the time of describing the arch of vibration compared with the former escapement where the action continues nearly to the whole extent of the vibration, and, therefore, not merely from the action being for a greater length of time, but because it continues to a part of the arc where the power or dominion of the pendulum becomes very small.

The friction of the tooth of the escapement upon the arched part of the crutch is, of course, the means of impeding, in a slight degree, the motion of the pendulum, and several methods have been invented in order to avoid this evil. Berthould effects this in a very simple manner by forming the arches so as to produce a very slight recoil by describing them from a centre at a small distance from that of the crutch, but this is not so effectual as the method employed by Mr. Mudge, represented in fig. 3.

(900.) Here, instead of allowing the tooth to drop on the back of the pallet, it drops on a detent o t a, of which the part t a is part of an arch whose centre is A, the centre of the crutch, and the part t o is in the direction of the radius. This piece does not adhere to the pallet, but is on the end of an arm o, which turns round the axis A of the crutch on fine pivots, but is made to apply itself to the back of the pallet by means of a slender spring attached to the pallet and pressing inward on a pin fixed to the arm of the detent. When so applied, its arch t a makes the repose, and the part a makes a small portion of the face a c of the pallet.

The action of this escapement will be easily understood. When a tooth escapes from the second pallet by the motion of the pendulum from the right to the left, another tooth drops on the pallet (which the figure shows to be the first or leading pallet) at the angle t, and rests on a small portion t a of an arch of repose. But the crutch, continuing its motion to the right, immediately quits the arm o, carrying the pallet a c along with it, and leaving the wheel locked on the detent o t a. When, on the return of the pendulum, it enters the arch of action, the pallet has applied itself to the detent o t a, and withdraws it from the tooth; this immediately acts

Mechanical
Processes.Graham's
escapement.
Fig. 2.Mudge's
escapement.
Fig. 3.

Manufactures.

on the face *ac* of the pallet and restores the motion lost during the last vibration. The use of the spring is merely to keep the detent applied to the pallet without shaking: it is a little bent during their separation, and adds something of an opposing force to the ascent of the pendulum on the other side of the wheel, and accelerates its return. A similar detent, *bd*, on the back of the second pallet, performs a similar office, supporting the wheel while the pendulum is beyond the arch of escapement, and quitting it when the pendulum enters that arch.

This is certainly a very considerable improvement; friction is almost annihilated by transferring it to the pivots at *A*, so that in the excursions beyond the angle of escapement it seems almost entirely free. Indeed, some artists have further reduced the friction of the pivots at *A* by making the arm of the detent a spring of considerable thickness, except near *A* where it is made very thin and broad; but it does not appear that this construction, although easily executed and susceptible of great precision and steadiness of action, is much practised. A part of the friction still remains which cannot be removed, namely, that which occurs while the arch *t a* is drawn from between the tooth and pallet, and, in fact, something more must be overcome here; for the tooth is apt to force the detent outward, unless the part *t a* be a little elevated at its point *a*, like a claw above the concentric arch, and the face of the tooth be made to incline forward so as to fit the shape of the detent. This will consume some force when the momentum of the pendulum is at its maximum, and should the clock be foul and the excursions beyond the escapement very small, this disturbance must be exceedingly pernicious. Dr. Robison also points out the following objection, *viz.*, that during the whole excursion beyond the angle of escapement there is a new force of a spring acting on the pendulum, which deviates considerably from the proportions of the accelerating power of gravity. It does not commence its action till the detent separates from the arm of the crutch, and then the spring of the detent acts as a retarding force against the excursion of the pendulum, now on the other side, bringing it sooner to rest and then accelerating it in its way back to the beginning of the arch of escapement.

(901.) Very similar to this (at least in the excursion beyond the angle of escapement) is the construction of Mr. Cummings, and it has the same defects. His pallets are carried in a similar manner as in the one described by the crutch: the detents press on them behind by their own weight only, and therefore when the tooth is locked on the detent of one pallet, its weight is taken off from the pendulum on that side, and the weight of the detent on the other side opposes the ascent and accelerates the descent of the pendulum.

Mr. Cummings executed another escapement consisting, like the above, of a pallet and detent; but the manner of applying the maintaining power is different in principle from any yet described. It is exceedingly ingenious, and seems to do all that is possible towards removing every source of irregularity in the maintaining power, and every obstruction to free motion arising from friction and oil in the escapement. Fig. 4, plate lxii., exhibits as much of this escapement as is necessary for explaining its general action; but those readers who wish to see all the minutiae of the construction must have recourse to the Work written by the author, as the complexity of the parts requires a more minute representation than our plan admits of. *A B C* is the

escapement or swung wheel, *D E* the pallets separately movable on the axis of motion, and having each a little ball or weight *H* and *I* supported by horizontal arms. Each pallet with its attached weight is separately movable from the other round its respective axis of motion, so that when one is raised by the wheel the other remains at rest. *F* and *G* are two detents firmly attached together like the ordinary pallets, or a common dead beat or recoil escapement, and are fixed to a cylinder of brass *P* that surrounds the two axes of motion of the pallets, which are in the same straight line, but separated from each other at the middle of the cylinder, where there is a partition that bears the interior pivot of one axis and the exterior one of the other; the crutch of the pendulum is also fast to the cylinder, so that the two detents and crutch move together with the cylinder without the motion of either pallet, and each pallet can move separately without the detents and crutch. *M* is a weight to counterpoise the detents and crutch in any position given them; and *n o* are two pins carried by the pendulum that project far enough to fall alternately in the way of the arms which carry the balls *H I* as the pendulum vibrates.

To explain the action of the escapement, let us suppose the different parts in the position shown in the figure, where the lever of the detent *G* is hid behind the lever of the pallet *E*, but may be conceived to be parallel to it; and the pallet *D* having been previously lifted from its quiescent position, where its point rested on the rim near the foot of the tooth *A*, then if we conceive the pendulum moving from right to left with the ball *I* urging the pin *o* attached to an arc fixed to the pendulum, the vibration is aided by the gravity alone of this ball. The arc that bears the pins *n* and *o* has a contrivance, not seen in the figure, for unlocking the detents at the moment when either of the pins bears against its ball. Conceive now the pin *n* brought into contact with the arm of the ball *H* by the motion of the pendulum; the detent *F* is unlocked and the tooth *A* of the wheel quits the end of the pallet *D*, the ball *H* now acts by its gravity on the pin *n* and descends at the same time aiding the returning vibration, while the pallet *D*, united to the arm of the ball *H*, descends also towards the wheel; but as soon as the pendulum first began its original vibration, the pin *o* was withdrawn from the pressure of the ball *I* by means of the attached pallet *E* falling on the tooth *C* of the wheel, so that all the latter part of the vibration was free; this pressure of the pallet *E* on the tooth *C* diminished the pressure of the tooth *A* on the detent *F* at the instant of unlocking.

The wheel, now in motion by the action of the maintaining power, goes on till the tooth *C*, acting on the pallet *E*, raises it outwards, together with its attached ball *I*, till the detent *G* stops the wheel's motion, when all the parts are at rest till the pendulum nearly finishes its returning vibration, and then its pin *o*, meeting with the elevated arm of the ball *I*, presses against it and concludes the vibration; at the moment the pressure is felt the contrivance we have mentioned above unlocks the detent *G* and allows the tooth *C* to escape; in the meantime the ball *I*, by its gravity, urges the pendulum for a short time, while the tooth following *A* meeting with the pallet *D* raises it and the ball *H* a second time, the following tooth comes in the way of the pallet *E* and stops the further action of the ball *I* on the pendulum, which now vibrates, as before, free, till its pin *n* again meets with the arm of the ball *H*, when the same

Cummings's escapement.

Fig. 4.

Manufac-
tures.

operation is repeated, and thus the weights H and I are alternately raised by the wheel, and then alternately act for a short time on the pendulum at the commencement of each vibration, so that gravity alone is, properly speaking, the maintaining power of the pendulum; and whatever may be the motive force it never affects the motion of the pendulum, but only raises the balls, which afterwards act alternately by the influence of gravity. Thus whatever may be the effects of oil, friction, wear, &c., on the action of the wheelwork, as it has no immediate connection with the pendulum except during the instant of unlocking the detents, these effects are almost entirely avoided as they regard the pendulum or regulating part of the motion.

The greatest objection in this construction is, that the additional gravity commences instantaneously, and also ceases instantaneously, and at a part of the vibration where the sudden exertion of any force is least favourable for aiding the simple gravity of the pendulum; it is also difficult of execution from being constituted of a great number of parts, and does not appear to have been found in practice superior to the simple dead beat.

Harrison's
recoil
escapement,
Fig. 5.

(902.) Notwithstanding the seeming superiority and great character which the dead beat escapement has long acquired over the recoiling one, the latter had its partisans; among whom were artists and amateurs possessed of the first-rate talents—Professor Ludham of Cambridge, Berthould, Smeaton, and others. Harrison also always rejected the dead beat; he constructed a clock with an escapement on the recoiling principle, invented by himself, which went for fourteen years without being touched, and during that time did not vary one complete second from one day to another, nor even deviated half a minute by accumulation from equable motion. We have given in fig. 5 a representation of this escapement; *g D o* is the swing wheel, of which *M* is the centre and *a* is the verge or arbor of the pendulum, provided with two short arms, *a b*, *a c*. A slender rod *b e* turns on fine pivots in the joint *b*, and has at its extremity a hook or claw, which takes hold of a tooth *d* of the swing wheel, when the pendulum moves from the right to the left. This claw, when at liberty, stands at right angles, or at least in a certain determinate angle with regard to the arm *a b*, and when drawn a little from that position it is brought back to it again by a very elastic spring. The arm *a c* is furnished with a detent *c f*, which also, when at liberty, maintains its position on the arm by means of a slender spring.

Let us suppose the tooth *d* is pressing on the claw *e* while the pendulum is moving to the left. The joint *b* yields, by its motion round *a*, to the pressure of the tooth on the claw, by which the angle *a b c* opens a little. In the mean time the same motion round *a* causes the joint *c* of the detent on the other side to approach the circumference of the wheel, and the tooth *g* at the same time advances; they meet, and the point of *g* is lodged in the notch under the projecting piece *f*; when it is evident that any further motion of the point *e* round *a* must push the tooth *g* a little backwards by means of the detent *c f*; it cannot come any nearer to the wheel because the point of the tooth stops the heel *f*. The instant the part *f* recoils from the tooth *g*, the tooth *d* is withdrawn from the claw *e*, which flies out by the action of its spring and resumes its position at right angles to *b a*; and the wheel being now free from the claw is pushing at the detent *f*. The pendulum having finished its oscillation

to the left (in which it causes the wheel to recoil by means of the detent *f*) returns towards the right, the wheel advances, and by pressing on *f* aids the pendulum through the whole angle of escapement. By this motion the claw *e* describes an arc of a circle round *a* and approaches the wheel till it takes hold of another tooth, viz., the one following *d*, and pulls it back a little, which immediately frees the detent *f* from the pressure of the tooth *g*, and it flies out a little from the wheel resuming its natural position by means of its spring; soon after the motion of the pendulum to the left ceases and it returns, being aided by the part *d* pulling forward the hook *e*.

Friction is nearly avoided in this escapement and oil entirely. The motion is given to the pendulum by a fair pull or push, and the teeth of the wheel apply themselves to the detents without rubbing. There is no drop, and the escapement makes no noise, and is for this reason called by the artists a silent escapement. By properly disposing the arms *a b*, *a c*, and disposing the pallets on the circumference of the wheel, the law by which the action of the wheel on the pendulum is regulated may be greatly varied so as to harmonize with the action of gravity.

It is, however, a recoiling escapement, and one, Dr. Robison remarks, of the worst kind; for the recoil is made at the very confines of the vibration, where every disturbance of the regular cycloidal vibration occasions the greatest disturbance to the motion. Yet this clock kept time with most unexampled precision, far excelling all that had been made before.

From this fact we may learn that the governing power or dominion of the pendulum is so great, that the action upon it from the maintaining power is not sufficient to influence, in a great degree, the irregularity of the vibrations; and that in a well-made clock with a heavy pendulum, any one of the escapements we have described, executed with pallets of agate and a wheel of hard steel, and the pendulum rod suspended, there will be hardly any difference observed in their performance; and thus has arisen the difference of opinions and controversies on the recoiling and dead beat escapement.

(903.) *Striking part of a clock.*—In the commencement of this article has been described one of the methods by which a clock is made to strike the hours indicated on the dial; but in modern clocks different means are employed, which, although rather more complicated and difficult of execution, have considerable advantages over the former, and are consequently generally preferred. If a clock provided with the count-wheel striking part be made to strike between the hours, by raising the detent it will strike the next following hour, and if again raised the next hour, and so on, successively increasing a stroke each time the machinery is put in motion; but in the latter method, the clock will continue to repeat the hour indicated on the dial for any number of times it is made to strike. This is a considerable advantage, as in the night the time may be known by simply pulling a string connected with a detent in the machinery; while a corresponding evil exists in the old striking part, from the inconvenience which results if, by any accident, the detent be raised so as to permit the clock to strike.

In plate lxii., fig. 6, is given the elevation of the front Pl. lxii. plate of a spring clock provided with this machinery; it exhibits the most important parts connected with the

Modern
striking ma-
chinery.
Fig. 6.

Manufactures.

striking; the position of the remaining parts, which are hid from view, are shown by dotted lines. The wheels A B C, with their respective pinions, convey the motion from the main wheel to the fanner D, which regulates the velocity by its resistance to the air. They are situated between the two plates of the clock frame, and are consequently shown dotted in the figure. The wheel A has eight pins, which lift the cross piece *e* of the arbor E eight times in each revolution of the wheel A. These elevations of the piece *e* occasion as many portions of a revolution of the arbor E, which has its pivot projecting behind the frame, and carries upon it the hammer E', which is consequently raised every time a pin of the wheel A moves the piece *e*. F is a long and powerful spring called the hammer tail spring, attached to the back part of the frame, which presses at its upper extremity under a cross pin passing through a hole in the arbor E, near the face of the back plate; so that when the hammer is raised at any time, the spring F urges it back again with a strong blow and makes it strike the bell, which is usually situated in these descriptions of clocks behind the frame, but is shown in a different position in the figure, in order that the action of the hammer may be more distinctly seen. To prevent the blow being too strong, a counter spring G is attached to the contiguous pillar of the framing, which breaks the violence of the blow and makes the hammer return smartly to its position when the blow is made; this spring also serves as a guard, in case the stroke of the hammer should be made when the bell is taken off at any time.

It will thus be seen that when the detent is removed, so as to permit the motion of the striking machinery, a number of blows will be given to the bell at intervals, governed by the resistance of the flyer or fan D. We have now to explain in what manner the machinery is put in motion at the end of each hour, and how the number of blows of the hammer is made to agree with that indicated by the hand on the dial. To the twelve-hour wheel is attached, by pins, an indented spiral piece of metal *a*, called the snail, (the shell of which it resembles in some measure,) which snail consequently revolves likewise in twelve hours; it has twelve steps upon the circumference, each of which subtends an angle of thirty degrees, so that, whether near to the centre of motion or remote from it, it is exactly the measure of an hour's motion of the twelve-hour wheel; *b* is a piece of steel called the rack, which is movable on a pin or stud at the lower angular point, near which the horseshoe spring *c*, called the rack tail spring, presses, to keep a pin on the remote end of this tail against the indentation or step of the snail, which happens to be contiguous to it; this pin is hid from the sight, but the place may be seen from the extremity of the tail where it is inserted. Above the rack is a horizontal steel bar *d f g*, movable round a stud *a d*, which is called the hawk's bill, from the bill or angular piece at *p* which engages the teeth of the rack. The piece *i i*, fixed to the projected part of the pivot of the wheel B near its lower extremity, and revolving with it, gathers up a tooth of the rack at each revolution, on which account it is called the gathering pallet; the catch of the hawk's bill, having a contrary slope, gives way in the mean time and comes back again by its own gravity. The wheel A has sixty-four teeth and eight pins, and its pinion has eight leaves, which therefore revolves once every time that the hammer of the bill is lifted, and as the gathering pallet takes

up a tooth of the rack at each revolution of its arbor, a tooth of the rack is taken up at each stroke of the hammer when the striking part is in motion. The angular piece *j k l* is called the warning piece; it is movable round an arbor at the angular part, and its lower end *l* falls in the way of a pin in the small hour wheel *m*, and its bent end *j* passes through an aperture *n* in the front plate of the frame, and is presented to a pin in one of the crosses of the wheel C of the striking movement within the plate, so as to restrain its motion when required to be in a quiescent state.

The action of the different parts is as follows: when the hawk's bill is lifted from the teeth of the rack by the pin upon the hour wheel, the spring *c*, pressing against the tail, makes it fall back till it meets with some obstacle to arrest its motion; that obstacle would be the pin *p* in the front plate, if there were no other interposed before it had fallen so far; but if the snail is in any other position than that wherein its indentation nearest the centre is contiguous to the pin on the rack tail, the tail pin on the rack will fall upon the edge of the snail before the rack has fallen back to the pin *u*, and all the teeth will not pass the hawk's bill, but only so many as there are indentations or steps from the remote angular point of the snail, to the step on which the tail pin rests; in the present position in the plate the tail pin is resting on the sixth step of the snail, which denotes that six strokes will be given by the hammer, or that six teeth of the rack are to be gathered up by as many revolutions of the hawk's bill; but it may be perceived that only five teeth remain to be gathered up by the rack; hence we know that the clock is in the act of striking, and has struck one out of the six. The pin in the hour wheel has just raised the warning piece and permitted it to go again; the clock will therefore continue to strike till the upper end of the gathering pallet falls on the projected pin *p* of the rack, which will be as soon as the last tooth of the rack is drawn up to the hawk's bill, in which situation the wheel *c* cannot revolve any further till another hour has elapsed.

When another hour has passed, the pin on the hour wheel will again elevate the warning piece *l*, the bent end of which will be raised out of the way of the pin of the wheel *c*, and the fly will run on a revolution or two with a whirling noise, *i. e.* the clock will give warning; but the end *g* of the hawk's bill has not been raised far enough by the end *j* of the warning piece to permit the catch *i* to clear the teeth of the rack, therefore the rack cannot yet fall back; presently, the hawk's bill is raised high enough by the continuation of the motion of the pin of the report wheel *m* and the rack falls back, till its tail pin rests on the seventh step of the snail, which has arrived during the interval of the hour contiguous to the pin on the rack tail, and there are in consequence seven teeth of the rack past the catch *i*, and therefore the hour seven will be struck before the tail of the gathering pallet falls again on the pin *p* of the rack and stops the striking; when at the same time the bent of the warning piece catches the pin of the wheel *c* and stops the motion of the fly.

It will thus be seen that the number of hours struck by the hammer will be regulated by the position of the snail, which revolving once in twelve hours, and being divided into twelve steps or indentations, each subtending an equal angle from the centre, a new step will be presented to the pin of the rack tail at the end of each hour, and an additional blow given by the hammer. It

Mechanical Processes.

Manufac-
tures.

will also be seen, that, as the snail or regulator of the number of strokes is not attached to the striking movement as in the count-wheel machinery, the striking may be repeated any number of times during the interval of an hour, or the passing of one step of the snail, and will indicate each time the same number of hours, so that the snail being placed in such a position with respect to the rack tail that a fresh step is presented to the pin the instant before the pin on the wheel elevates the warning piece, the passing hour will always be struck any time the machinery is permitted to work, until the instant the new hour commences.

This striking part may, therefore, be readily converted into repeating mechanism; and the drawing given in the plate, taken from a clock in which the additional parts necessary to effect this are added, we have chosen in order to illustrate the principle upon which the repeating watches and clocks are constructed. A lever $q q$ is situated in front of the plate, one end of which engages a pin on the warning piece, and the other extends beyond the case of the clock, and is provided with a line which is at all times accessible; the lever turns upon a pivot or stud at r , and is provided with a spring to return to its original position; it will thus be seen that, as often as the string is pulled, the catch will be raised clear of the rack, and the striking mechanism will be put in motion and will indicate, however often repeated, the strokes of the current hour. It still remains to explain the three-armed piece $s t u$, which is called the strike or silent, by the use of which the clock may be made to strike at any part of the hour, or the striking mechanism totally detached from the clock's movements so that the clock will revolve from hour to hour without striking. This piece is made movable on a socket rivetted to the end u of one of the arms, round a stud in the front plate of the frame, and as the socket has scarcely any shake or lateral motion, the other two ends s, t move always in the same plane. At the end marked s is a pin which projects beyond the upper part of the face or dial of the clock, so that it may be moved to the right or left at pleasure, when the glass door is open; the end t has a slope like a wedge on that side which is next to the plane of the plate frame, and the end of the arbor situated within the frame on which the warning piece is fastened projects so far as to touch the inclined plane; this arbor of the warning piece has some shake or is seen to move in the direction of its length. Its posterior pivot passes between the prongs of a forked spring, which, resting against its shoulder, pushes it close to the interior side of the front plate of the frame where a similar shoulder stops it.

When the pin at s is pushed to the right, the wedge of the end t pushes the arbor back notwithstanding the forked spring, and the end l of the warning piece being carried with its frame nearer to the arbor than it otherwise would be, falls in the way of the pin of the hour wheel, and the clock consequently strikes the hour regulated by the snail, and if left in that position, the clock will again strike at the end of one hour; but if the pin at s of the strike or silent is pushed to the left, the end t is withdrawn from the pivot of the arbor on which the warning piece is fast, the spring in the frame pushes it forward so far that the end of the warning piece is clear of the pin of the hour wheel, which continues to revolve from hour to hour completely detached from the mechanism of the striking part.

This ingenious striking machinery, although an invention of long standing, does not appear to have been improved upon, and is still continued to be preferred. Among the many inventions appertaining to clockwork which have been rewarded by the Society of Arts will be found several on the striking mechanism; but as they do not appear, from what we are able to learn, to be generally adopted, we have not entered into a description of them, but beg to refer the reader to vols. xxi., xxix., xxxv., and xxxviii., of the Society's *Transactions*. Striking machinery of very ingenious construction is also described in several of the Works enumerated at the end of this article.

Mechanical
Processes.

Construction of Watches.

(904.) Having in the preceding pages explained the construction of that description of timekeepers whose governing power is a pendulum, termed clocks, we return again to that part of the history of these inventions when the pendulous properties of the spring were discovered, and when portable clocks or watches assumed a form and dimensions totally different from that of the clock. Although the form and arrangement of these two instruments are so very different, the principle upon which the regulation is effected is the same in both, the office of the weight or maintaining power being supplied by a spring, and the vibrations of the pendulum by those of the balance and spring. These latter maintaining and regulating powers are equally perfect with those of the clock in a theoretical point of view, but are much inferior in their action; and although chronometers have been brought to a degree of perfection truly surprising, they will probably never equal in their performance a well-made clock; a conclusion which one is not only led to by experience, but which simple reasoning on the nature both of the maintaining and regulating power will readily point out. In the first place, the power of a spring must be subject to irregularities as it relapses, which, although compensated for in a great measure by the action of the fusee, cannot possibly be entirely corrected, and certain irregularities from this cause will creep in which are additional to those of variations of friction to which a clock is subject. Again, the regulating power of the balance has much less control or dominion than that of the pendulum, and is, consequently, less able to correct the same irregularities; and although by the beautifully contrived escapements of Earnshaw and others its natural vibrations are but little interfered with, yet in making a comparison of the performance of these two machines, where an equal degree of skill and workmanship have been displayed, the clock must necessarily, from the superior dominion of the pendulum, approach nearest to true time.

Notwithstanding, however, the clock has the precedence of the watch or chronometer in point of its perfect measurement of time, still its uses, though highly valuable to Science generally, and to Astronomy in particular, are far less important than those of the chronometer, the use of which is so practically valuable to the sailor, who by its aid is able to traverse the ocean with a degree of confidence and safety which could not be arrived at by any other means.

Before we proceed to describe the successive inventions which have produced the present improved state of this instrument, it will be necessary to give a drawing and explanation of the construction of the common

Construc-
tion of
watches.

Manufactures. watch which has remained with the same escapement and nearly in the same shape as when first invented.

Description of a common watch. Plate lxxiii, fig. 1 and 2, is the plan and elevation of the works of a common watch, the position of the different parts in the elevation being a little deviated from that in which they would be seen in viewing the watch, in order that their action may be more clearly understood, but the position and manner of arrangement will be readily perceived from the plan. The moving power is a spiral steel spring which is coiled up close, by a tool used for the purpose, and put into a brass box called the barrel; the spring has a hook at its outer end which is put through a hole in the side of the barrel and rivetted, and the inner end has an oblong opening cut through it to receive a hook upon the barrel arbor. This arbor extends through the bottom of the barrel, and is made square to hold a worm or tooth wheel *d*, which is turned round by a worm and serves to adjust the action of the spring to that of the fusee; the end of the arbor projects beyond this and is attached by a pivot into the lower or face plate *A* of the watch; the top of the barrel has a cover put over it, through which the pivot of the arbor projects and works in a socket in the upper plate *D*.

The barrel thus mounted has a steel chain *a*, hooked to the upper part and coiled round, the other end of which is attached to the fusee *E*. It is thus evident that when the fusee is turned by the watch key it will wind the chain off the barrel on itself; and, as one end of the spring is fastened to the barrel and the other end to the arbor, (which is prevented from turning by the worm wheel beneath,) the spring will be coiled up in a smaller compass than it was before, and by its reaction will, when the watch key is taken off, act on the fusee and exert a force to turn the movements of the watch. The fusee has a spiral groove cut round it in which the chain lies; this groove is cut by an engine in such a manner that the chain shall pull from the smallest part of the fusee when the spring is wound up, and acts with its greatest force, and gradually increases in size as the spring unwinds and acts with less power, so that the motive power of the watch may be always the same. For the action to be always equal, the strength of the spring, at any state of unwinding, should be inversely in proportion to the radius or diameter of the fusee, which is the lever by which it acts. This is effected by adjusting the position of the spring with respect to the fusee by the worm *b*, which turns up the spring and causes it to act with greater force. By this adjustment the power of the spring at the commencement and completion of its action, being made in proportion to the respective diameters of the fusee upon which the chain is coiled, the intermediate states of the spring, from the particular curve given to the fusee, will be exactly in the correct proportion, and an equable action on the works produced.

The fusee has a ratchet wheel at the lower end which engages a click fixed in a hollow cut in the great wheel *e*, in order that when the watch is being wound up the fusee may slip round without the wheel, but that when, by the action of the spring, it is turned in the contrary direction, it engages this wheel, and thus puts the works of the watch in motion. The great wheel has forty-eight teeth on its circumference, which engage and turn a pinion of eight teeth fixed on the same axle with the centre wheel *g*, which has fifty-four teeth, and engages a pinion of six leaves on the axle of the third wheel *h*: this wheel has forty-eight teeth and turns

a pinion of six teeth on the axle of the contrate wheel *i*, which has forty-eight teeth cut parallel to its axle by which it turns a pinion of six leaves fixed to the balance wheel *k*. The pivots of the axle of this wheel turn one in a frame *F*, called the potance, fixed to the upper plate, and the other in a small piece called the counter potance, so that when the two plates are put together the balance wheel pinion may work in the teeth of the contrate wheel. The balance wheel has fifteen teeth by which it impels the balance *l*, the axle of which, called the verge, has two pallets projecting from it nearly at right angles to each other; these are acted upon by the balance wheel, as shown enlarged in fig. 4, where the lower pallet is supposed to be in contact with one of the teeth of the balance wheel, which as it turns pushes the pallet round and the balance with it, till the balance has made about a quarter of a turn, the tooth of the balance then slips off and escapes. In this position the watch would run down if it were not for the upper pallet at that instant engaging another tooth on the opposite side of the balance wheel, which, as it moves in a contrary direction, pushes the balance back again till the tooth escapes the pallet, the lower pallet then engages the wheel as before, and thus the action is continued; *m* is the pendulous spring which is made of steel and of a spiral figure; the inner end of it is fixed to the verge just beneath the balance, and the outer end pinned to a stud fixed to the top of the upper plate of the watch, so that the balance will rest only in one position, and if it is moved either way by the balance wheel the spring will have a tendency to bring it to the same position again. When the lower pallet, for instance, has just liberated a tooth of the balance wheel, the pendulous spring is strained and returns the balance to its point of rest instantly, the balance wheel following the upper pallet by the action of the main spring; the balance will, of course, by the momentum which it has received, vibrate past its natural point of rest, but this is, by the assistance or force of the main spring upon the pallet, made to vibrate sufficiently in the other direction to permit the tooth to pass.

It is evident that, by lengthening or shortening this spring, the velocity of the balance will be regulated; this is done by a contrivance shown in fig. 5, consisting of a plate of brass screwed to the top of the upper plate; at one place it is hollowed out to receive a wheel *n* of twenty teeth, which turns a segment of a wheel *p* called the curb; this moves round in a circular groove, which has a projecting leaf *q* with a notch in it to receive the pendulous spring, so that by turning the wheel with a key put on the square part of the axle, the spring is lengthened or shortened so as to give a different power and make the balance vibrate quicker or slower: the axle of the wheel has a hand upon it which works round upon a graduated dial, so that when the rate is altered it may serve as a guide to set it by. The upper pivot of the verge runs in a cock screwed to the upper plate, which covers the balance and protects it from violence, and the lower pivot works in the bottom of the potance; the socket of the pivot of the balance is made in a small piece of brass which slides in a groove made in the potance, so that by drawing the slide in or out the teeth of the balance wheel shall just clear one pallet before it engages another.

The watch is so adjusted by the spring that the balance shall vibrate so as to turn the centre wheel round once in an hour, the spindle of which projects

Mechanical Processes.

Fig. 4.

Fig. 5.

Manufac-
tures.

through the lower plate, fig. 1, and has a tube fitted on it which is square at the top and carries the minute hand the other end of the tube has a pinion of twelve teeth on it which turns the minute wheel *s* of forty-eight teeth, and its pinion of sixteen, and this moves the hour wheel *t* of forty-eight teeth; the spindle of this is a tube which is put over the tube of the minute hand, and has the hour hand fixed upon it, and thus the time is indicated upon the dial plate to the degree of minutes, which is sufficiently near for common purposes. If the watch be required to show seconds, it is only necessary to continue the axle of the wheel to the dial plate and to affix a hand to it.

Balances of Watches.

Discovery
of the
isochronal
property of
the spring

(905.) The balance, by the aid of a spiral spring, performs the office of a regulator to watches, on the same principle as the pendulum does to the clock, that is, it performs oscillations in the same time when undisturbed by foreign forces, whether they be wide or narrow. For the discovery of the isochronal properties of the spring, we are, as already stated, indebted to Dr. Hooke; for although the honour of this invention is disputed with him by Huygens, there appears to be most unquestionable evidence of Dr. Hooke's priority by fifteen years. He found that the force necessary for retaining a spring in any constrained position was proportioned to its tension or deflection from its natural form. This fact, which the doctor immediately conceived might have important practical applications, he expressed and published in the form of an enigma, which was the practice of the times; the letters of which were *ce u i n o s s t*, *t, i z*, which was explained some years after by *Ut tensio sic vis*. But this property of the spring, although its application has been so important, does not seem to be strictly borne out by theory, as in the case of the accelerating action of gravity on the pendulum. Dr. Robison was of this opinion. He remarks, "that the proof of this principle rests entirely on the nicety and propriety of experiments, and long experience has shown that it is true only within certain limits." The approximation, however, is a very close one, and the application itself one of the highest importance; but in its simple state other irregularities besides those which belong to the natural elasticity of the spring occur, which require compensation similar to those of clocks; the effect of temperature are no less sensibly felt here than in the larger machine, and much ingenuity has been exercised in correcting these defects by the invention of what are termed compensation balances, which we shall now proceed to describe.

Compensation Balances.

Compensa-
tion ba-
lances.

(906.) As the velocity of the vibrations of a balance depends both upon the strength of the pendulous spring and the distance of the centre of oscillation from the point of suspension, the changes of temperature will have great influence on the rate of a watch, not merely by the expansion of the balance, which, of course, increases the radius of the centre of oscillation, but also by weakening the power of the pendulous spring, both of which effects tend to make a watch lose by an increase of temperature. We may even add to these the expansion and consequent decrease of power of the main spring, or motive power, the influence of which tends in the same manner

to make the watch lose. In the common watch these effects are, in some measure, compensated by the variable fluidity of the oil applied to the pivot holes of the balance arbor and of the other arbors of a watch, which are affected by a change of temperature in an opposite manner to that of the springs and balance; that is, an increase of temperature, by rendering the oil more fluid, gives more freedom to the action of the maintaining power and balance, and thus counteracts, in some measure, the expansion and lengthening of the springs.

Mechanical
Processes.

This natural compensation, which is very useful in the common watch, as it enables it to approach much nearer than it would otherwise do to correct time, is very inconvenient to the chronometer maker, as it interferes with the effects produced by the latter compensations, by the uncertainty and irregularity of its action, which, of course, will not admit of that degree of measurement and adjustment which the compensation by the expansion of metals will afford.

As the change of rate in a chronometer is much more than is due to the simple expansion of the balance, the correction which could be afforded by the counter expansion of another metal in the same manner as in the pendulum, would not be sufficient to effect the purpose, and the more powerful means of the change of figure of two laminæ of different metals placed together is had recourse to. In these ways the effect of heat is rendered very sensible, so much so that two thin laminæ of brass and steel placed together will curl up instantly by the heat of the hand, and as suddenly resume their original figure. It does not, however, require the aid of experiments to perceive that the effect of heat will be readily shown in this manner, when we consider that if the outer metal is expanded 3.1416 times the thickness of the inner one, the figure, if originally straight, will assume a semicircle, a degree of expansion which will be attained very readily by a small change of temperature, by having the laminæ thin and long.

Having thus attained a ready means of affording compensation, the best manner of its application becomes an important consideration. It is done in three different ways, *viz.*, first, by causing it to act exclusively on the balance itself; secondly, partly on the spring and partly on the balance; and, thirdly, exclusively on the balance itself. This latter method, although not the most modern, is the one now commonly employed, and to which we shall chiefly direct our attention.

There is every reason to believe that Harrison was the first who employed a compensation to a time-piece; but the first pocket watch made in Europe with a compensation was by F. Berthoud. It was begun in 1763, finished the beginning of 1764, and was sold in London to Mr. Pinchbeck for his Britannic Majesty King George III. The compensation acted on the spring, and was effected by laminæ of brass and steel pinned together, one end of which being fixed to the potance plate outside, the other acted on a short arm projecting from a movable arbor, a longer arm having the curb pins in it which were made to move nearly in the circle of the outer coil of the spiral spring.

Mudge, some time before the year 1770, made a watch for Mr. Smeaton, in which the compensation was also of the first class, and was effected by two long strips of brass and steel soldered together; the united piece was coiled or turned up into a spiral sufficiently close together in the coils to be free. The inner end was

Harrison's
compensa-
tion.

Berthoud's
compensa-
tion.

Mudge's
compensa-
tion.

Manu-
facture.

fixed to a circular, curbed tooth wheel, a short portion of the outer end had a sort of pivot formed on it bent in the circle of the outer coil, and supported by a small stud fixed in the curb wheel, having freedom to move easily in a hole in this stud. At this end were the curb pins, between which the pendulous spring played.

Berthould, Arnold, and others had recourse to different modes of compensation before they arrived at that one which gave them complete satisfaction. The former in his first machines used small wires of brass and steel, combined nearly like the gridiron pendulum; to those of a later date was applied a straight piece composed of laminæ of brass and steel pinned together, acting on the arm of a short lever, and on the end of the other arm, which was of some length, the curb pins were fixed. Even with those balances, which were composed of brass and steel pinned together, he adopted, as a supplementary aid, the straight compensation piece with the movable arm and curb pins.

Arnold's
compensa-
tion.

In Arnold's balances two pair of laminæ were placed parallel to the diametrical arms: on the middle of each of the combined laminæ was fixed a small wire which came through the rim of the balance, outside of which, and on the end of the wires, a small ball was fixed to each, which were pushed out or drawn in by changes of temperature.

Pl. lxiii.
Fig. 8.

Plate lxiii. fig. 8, is a representation of the compensation balance of Arnold; *ab* is a steel rim on which three pieces of metal are situated so as to slide, in order to adjust, in some degree, the equilibrium of the balance; *cc* are pieces of gold which turn spring tight on the tipped parts formed from the ends of the steel laminæ; *ee* are small screws put in through the compound laminæ which serve to adjust for small differences in the same way as the mean time screws *dd* do for greater portions of time.

Earnshaw's
compensa-
tion.
Fig. 9.

In fig. 9 is represented the compensation balance employed by Earnshaw: *dd* are pieces having a groove turned in them by which they engage the compound rim of the balance, and can be made to slide backward and forward on it; *cc* are the screws which fix them to the rim after the adjustment for heat and cold is completed; *aa* are the screws which adjust to mean time.

The chronometer when completed is put in an oven, and if it is found to lose in its rate, it shows that the compensation is not sufficient, and the adjusting pieces *dd* must be moved along the bar of laminæ towards the point of attachment; if, on the contrary, it is found to gain in its rate, it shows that it is over-compensated, and the adjusting pieces must be moved in the contrary direction, in each case taking care that the two pieces are moved in an equal degree, in order that the balance may be preserved.

These balances are now very commonly constructed with screws in the rim, by which the adjustment is effected instead of by the movable piece *d*. When upon trial it is found that the watch is not sufficiently compensated, one of the screws must be removed to a hole further; the point of attachment of the rim and of the compensation is then found to be a little in excess, and it may be remedied by unscrewing it so as to remove it further from the rim, or by changing its position with a screw of less weight. This construction will be understood from fig. 10, which is taken from the balance of a chronometer constructed by Parkinson and Frodsham.

Fig. 10.

Many other modes of compensation have been invented and are employed which are equally efficient in

VOL. VIII.

their action; but as they are all founded on the same principle, we do not conceive it necessary to enter any further on this subject, and shall, therefore, employ what our limits will permit to explain as fully as possible the many beautiful inventions for the escapements of watches which have ultimately brought this instrument to so high a degree of perfection.

Mechanical
Processes.

On Escapements of Watches.

(907.) Although the vibrations of a balance aided by a spring, when uninfluenced by any foreign force, will be perfectly isochronal, yet it is evident from the little weight they possess compared with a pendulum, the heaviest seldom exceeding twenty grains, that they have no means of accumulating such a power over the wheelwork as a pendulum. The execution of the proper escapement for watches is, therefore, a far more difficult and delicate task than in the case of a clock, not only for the above reason, but because the scale upon which it is executed is so much less. To make up for the deficiency of momentum in the balance the weight is accumulated chiefly in the rims, and the vibrations are made very wide and extremely frequent. The balance rim of a middle good watch should pass through at least ten inches in a second; yet with this advantage the momentum is a mere trifle compared with a pendulum; and as Dr. Robison observes, in his elegant Treatise on watchwork, "When we reflect on the small momentum of this regulator, the inevitable irregularities of the maintaining power, and the comparative magnitude even of an almost insensible friction or clamminess, it appears almost chimerical to expect any thing near to equality in the vibrations and incredible that a watch can be made which will not vary more than one beat in 86,400." Yet each have been made, and they must be considered the master exertions of human art.

Watch and
chronome-
ter escape-
ments.

The common recoiling escapement of the old clocks still holds its place in the ordinary pocket watches; but such watches are subject to great variation in their rate of going, by any change in the motive power; which is evident, for if the watch be held backward or pressed forward by the key applied to the fusee, we hear the beating greatly retarded or accelerated. The action of this escapement has been already explained in its application to the pendulum. It is therefore unnecessary to repeat it; but it must be very evident that the maintaining power being applied in the most direct manner, and during the whole of the vibration, that it will have the greatest possible influence in moving the balance; it is therefore remarkable its use is still continued in watches, when those of modern construction, which are equally simple and infinitely superior in their action, can be applied at nearly the expense.

(908.) *Graham's escapement.*—The first improvement of importance that was made in the escapements of watches was by Graham, who introduced the cylinder tooth to act in the same manner as his dead beat in clocks; and which was called the horizontal escapement. In this, as in the dead beat for clocks, the tooth of the scape wheel rests, during the greater part of each vibration, on a cylindrical surface, and acts on the inclined plane, for a short time only, in the middle of each vibration; so that a change in the maintaining power scarcely produces a sensible derangement of the isochronism; for whichever way we turn the key of a horizontal watch, as long as it continues to go, the frequenting of the vibrations is

Graham's
escape-
ment.

Manufac-
tures.

Pl. lxiv.
Fig. 1.

scarcely effected. A drawing of this escapement is given in plate lxiv. fig. 1, where D E represents the rim of the balance wheel; A and C are two of its teeth having their faces formed into planes inclined to the circumference of the wheel in an angle of about fifteen or twenty degrees. Suppose a circular arch A B C described round the centre of the wheel and through the middle of the faces of the teeth. The axis of the balance passes through the same point B of this arch, and we may say that the mean circumference of the teeth passes through the centre of the verge. On this axis is fixed a portion of a thin, hollow cylinder *b c d*, made of hard tempered steel or of some hard and tough stone, such as ruby or sapphire; agates are sufficiently hard but brittle, and chalcedony and cornelian are sufficiently tough but inferior in hardness. This cylinder is so placed on the verge that when the balance is in its quiescent position, the two edges *b* and *d* are in the circumference which passes through the points of the teeth; by which construction it will occupy 210° of the circumference, or 30° more than a semicircle. The edge *b*, to which the tooth approaches from without, is rounded off on both angles. The other edge *d* is formed into a plane inclined to the radius about 30° .

Now, suppose the wheel pressed forward in the direction A C; the point *b* of the tooth touching the round edge will push it outwards turning the balance round in the direction *b c d*; the heel of the tooth will escape from this edge when it is in the position *h* and *b* in the position *i*, the point *b* of the tooth being at *d*, but the edge of the cylinder arrived as far as *i*. The tooth, therefore, rests on the inside of the cylinder while the balance continues its vibration for a short distance, in consequence of the impulse which it has received from the action of the inclined plane. When the vibration is ended by the opposition of the balance spring, the balance returns, the tooth (now in the position B) rolling all the time on the inside of the cylinder. The balance comes back again into its natural position *b c d* with an accelerated motion, by the action of the spring, and would of itself vibrate nearly as far on the opposite side, but is aided again by the tooth, which, pressing on the edge *d*, pushes it aside till it come into the position *k* when the tooth escapes from the cylinder altogether. At this moment the other edge of the cylinder is in the position *b*, and the tooth in the position A. When this vibration in the direction *d c b* is finished, the verge resumes the same position by the action of the spring, and the tooth begins to act on the first edge *b*, pushes it aside, escapes from it, and drops on the inside of the cylinder. In this manner are the vibrations produced gradually increased to their maximum and maintained in that state. Every succeeding tooth of the wheel acts first on the edge *b* and then on the edge *d*, resting first on the outside, and then the inside of the cylinder; and thus the balance is under the influence of the wheels while the edge *b* passes to *h* and while *d* passes to *k*, and the rest of the vibration is performed without any action on the part of the wheels, but is of course a little obstructed by the friction and by the clamminess of the oil, which is however so small, if a little fresh oil be frequently applied, that a timekeeper with a dead beat of Graham has been made which does not vary from true time two parts in a million.

Still, however, the friction of the teeth of the escape wheel on the cylinder or pallet, and the tenacity of the oil where it is employed, may interfere in a slight degree with the time of vibration, especially by the

irregularity to which they are liable. If the friction were perfectly uniform, it would scarcely disturb the isochronism, but friction is always increased by an increase of pressure, hence, therefore, any addition to the sustaining force must tend, in some degree, to retard the vibrations; and to obviate this, the surfaces on which the teeth rest have sometimes been so formed as to create a slight recoil; but this construction does not appear to have been very successful in practice.

(909.) *Duplex escapement*.—The friction is considerably reduced by the duplex escapement, apparently so called from a double series of teeth being employed which is now frequently adopted in pocket chronometers. The teeth of the most prominent series are detained on a cylinder so small as to be unfit for receiving an impulse from them; the balance is therefore impelled by the other series of teeth acting on a pallet a greater distance from the axis. The construction and action will be better understood from the drawing, fig. 2, where A D is the balance wheel, having teeth *f b g* at the circumference. These teeth are entirely for producing the rest, while the balance is making excursions beyond the escapement which is effected by means of an agate cylinder on the verge. This cylinder has a notch *o*, so that when it turns in the direction *o p q* the notch easily passes the tooth in the position B which is resting on the cylindric surface; but when it returns in the direction *q p* the tooth B gets into the notch and is pressed on one side till the notch comes into the position *o*. The tooth being then in the position *b* escapes from the notch, and another tooth drops on the convex surface of the cylinder B.

The balance wheel is also furnished with a set of stout, flat-sided pins standing upright on its rim, as represented by *a D*, and there is also fixed on the verge a larger cylinder C F C above the smaller one *o p q*, with its under surface clear of the wheel, and having a pallet C of ruby or sapphire firmly indented into it and projecting so far as just to be clear of the pins on the wheel. The position of this cylinder with respect to the smaller one below it is such that, when the tooth *b* has escaped from the notch, the pallet C has just passed the pin *a*, which was at A while B rested on the small cylinder, but it moved from A to *a* while B moved to *b*. The wheel being now at liberty, the pin *a* exerts its pressure on the pallet C in the most direct and advantageous manner, and gives it a strong impulsion, following and accelerating it till another tooth drops on the little cylinder. The angle of escapement depends partly on the projection of the pallet, and partly on the diameter of the small cylinder, and the advance of the tooth B into the notch. Independent of the action of the small cylinder, the angle of escapement would be the whole arch of the large cylinder between G and *h*, but *a* stops before it is clear of the pallet; and the arch of impulsion is shortened by all the space that is described by the pin while the tooth moves from B to *b*.

The French have employed a construction somewhat similar to this, termed the *échappement à virgule* or comma escapement, because the pallet resembled a comma in shape. The teeth first rest on a small arch of repose, and then impel the curved surface of a pallet extending to a considerable distance beyond it. In both these cases the single pallet, which is impelled by a tooth of a simple form, requires less labour in the execution than a number of larger teeth, each of which is to be finished with great accuracy; see fig. 6. Somewhat similar to this is Tompion's escapement, fig. 7.

Mechanical
Processes.

Duplex
escape-
ment.

Fig. 2.

Comma
escape-
ment.

Fig. 6, 7.

Manufac-
tures.
Remontoir
escape-
ment.

Remontoir escapements.—This term remontoir has been applied to escapements in which the maintaining force is applied to the balance by the intervention of a spring which, being bent up at intervals by the maintaining power, acts upon it independently, by which contrivance the balance was considered to be made free and uninfluenced by any change of the maintaining power.

There have been several escapements on this principle invented, the earliest of which was about the year 1600, and is described by Huygens in his *Horologium Oscillatorium*. Harrison employed one in the chronometer which obtained the Parliamentary reward; but the escapement by Mudge appears to have been that in which the principle has been applied with most effect: the following description of it may therefore be interesting.

Mudge's
escapement.

(910.) *Mudge's escapement.*—The basis of this escapement is the old crown wheel and verge, but in place of the verge being in one piece, having two pivots and the balance rivetted on it, let us conceive that each of the pallets of the verge has an arbor and two pivots, and that the balance is on a double-kneed crank, having a pivot at the end of each knee, one of which may be called the foot pivot, the other the balance pivot; the piece of steel from which this last is turned being on the collet on which the balance is rivetted. These pivots and those of the pallet arbors are in one upright line, coinciding and concentric with one another, having their motion free and independent of each other, unless when in these parts of the action of the escapement, the face of the pallets in place of being flat are hollow, or a little curved, having a nib at the edge to lock the wheel by. The reader will better be able to understand the construction, which consists of a considerable complication of parts, by reference to fig. 6, 7, plate lxiii., where A A is the escapement wheel, B B the balance, the verge or axis of which, C C, is a crank; F the upper pendulum spring, by means of which the vibrations of the balance are regulated; G the pendulum spring stud, and H the pendulum spring, which is acted upon by the compensation pieces; D a and E b are two compound pieces which communicate the motion from the balance wheel to the balance, and consist of the following parts, viz., the projections or pallets *l m*, fig. 7, which are acted upon by the teeth of the balance wheel, and were made of black flint in the original timekeeper, but they may be made of ruby, sapphire, or other hard stone; *a* and *b* are steel arms which act upon the pins *c d* of the balance crank; *e* and *f* the impelling springs which are attached to the arbors of the pallets at the inner ends, and to the studs *g* and *h* at the outer ends; *i* and *k* small screws, which fix the pallets to the arbors by means of the clamps or pieces of steel D and E. Having mentioned all the parts of the escapement, we will now endeavour to describe its action.

When the pallet is raised by the balance wheel (as appears in fig. 7) it is kept from going any further by the hook at the end of it, until the pin *d* in the crank meets the arm *b*; for then the crank will carry on with it the arm *b* to the end of its vibration, and at the same time the tooth of the wheel will be disengaged from the above-mentioned hook. Afterwards, as the crank returns, the arm *b*, actuated by its spring *f*, will communicate an impulse to the crank, and soon after its crooked part will rest against one of the teeth of the wheel which again raises the pallet. With respect to the balance wheel, as soon as its tooth is disengaged from the pallet by the means above stated, it raises

the pallet *m*, which, on the returning vibration of the balance, is, by the pin *c* acting on the arm *a*, carried on in a contrary direction, after the manner of the other pallet; and thus the springs attached to the two pallets alternately give their auxiliary aid to the vibrations of the balance.

Mechanical
Processes.

Several other escapements on this principle have been invented; but as their use is entirely supplanted by the escapements generally known by the name of the detached escapements, we conceive it unnecessary to enter into a further description of them, and we complete the article by a full description of the perfect escapements of Arnold and Earnshaw which are now almost invariably used in the best chronometers.

In the Memoirs of the Academy of Paris for the year 1748, and in the collection of approved machines and inventions, we have descriptions of this contrivance, the principle of which, it appears, was first applied to chronometers by Le Roy. The balance wheel rests on a detent, while the balance is vibrating in perfect freedom; it has a pallet standing out from the centre which, in the course of vibration, passes close by the point of a tooth of the wheel. At that instant a pin, connected with this pallet, withdraws the detent from the wheel, and the tooth just mentioned follows the pallet with rapidity and gives it a smart push forward. Immediately after, another tooth of the wheel meets the other clog of the detent and the wheel is again locked; when the balance returns, the pin pushes the detent back into its former place where it again locks the wheel; and the balance again resuming its first direction unlocks the wheel, and receives another impulse from it: and thus the balance is unconnected with the wheels except while it gets the impulsion and at the moment of unlocking the wheels.

Roy's
escape-
ment.

The principle was applied by Mr. Arnold and Earnshaw to the chronometers which were rewarded by the Board of Longitude in the year 1805. The escapements very much resembled each other; the chief difference being that Mr. Arnold employed an epicycloidal tooth acting on a single point of the pallet, and Mr. Earnshaw makes a flat surface of the tooth first act on the point of the pallet, and then the point of the tooth on a flat surface of the pallet. We have given the descriptions of each delivered by the authors, with models of each escapement, to the Board of Longitude, omitting, however, such parts as relate particularly to the model, and are not essential in explaining the principle of the invention.

(911.) *Arnold's escapement.*—A A A, fig. 3, pl. lxiv. represents the escapement wheel, the teeth of which are of a cycloidal shape, and whose upper surface towards the extremity presents to the view a triangular form, two sides of which are described by right lines, and the other by a cycloidal curve, which is the principal part of action.

Arnold's
escape-
ment.
Pl. lxiv.
Fig. 3, 5.

B B *d*, the escapement or locking spring, screwed fast by its end C to a pillar, and extending from C to *d*, in the direction C N *d*. The centre of motion of this spring is between C and N, the part N *d* being more substantial than the part C N.

The locking piece or locking pallet is shown at *a*, whose acting surface is a jewel placed between N and B, and opposite the end of an adjusting screw F, which pallet, descending from the escapement spring, locks upon the interior angle of the tooth 2, (and upon every tooth in succession,) suspending the motion of the escapement wheel A A A for a time, and leaving

Manufac-
tures.

Pl. lxiv.
Fig. 5.

the balance to vibrate without interruption from any part of the machinery. It is to be observed that the triangular parts of the teeth of the wheel *A A A* (the wheel being hollowed or sunk) are raised above the periphery of the wheel to meet the locking piece *a*, so that, upon viewing the wheel edgewise, as in the elevation, (fig. 5,) the teeth will appear broader than the edge of the periphery *b*.

N e is the discharging or unlocking spring which is attached to the escapement or locking spring *B B d* at *N*, and passes (under the adjusting screw *F*) a little beyond the end *d* of the locking spring. This discharging spring is made very delicate and slight.

F is the adjusting screw, supported by the pillar *g*, whose end is opposite to the locking piece or pallet *a*, on the contrary side of the escapement or locking spring *B B d*, and by which the locking piece or pallet *a* may be more or less advanced upon any tooth of the wheel *A A A*, the escapement spring *B B d* always pressing the locking pallet *a* against the end of the screw *F*, except at the time of unlocking the wheel.

o is the unlocking, discharging, or small pallet, whose acting part is a jewel. This pallet, when the balance is in motion, presses against the end of the discharging spring at *e*, and passing on in a direction from *e* to *d*, carries with it for a short space the discharging spring *N e*, and also the locking spring *B B d*, moving them both at the same time, and in so doing carries the locking piece *a* from off the interior angle of the tooth 2, (or any other tooth which may come into that situation,) and leaves the wheel *A A A* at liberty to impart its power to the impelling pallet. But when the balance returns, and the unlocking pallet *o* repasses the discharging spring *N e*, in a direction from *d* to *e*, it does not in the least disturb the locking spring *B B d*, nor consequently the locking piece or pallet *a*, but moves only for a short space the unlocking spring *N e*.

H H H, the impelling or large pallet, whose acting part is at the angle *m*, where a jewel is placed. Upon the exterior of this angle the pallet receives its impulse from the cycloidal part of the teeth of the escapement wheel *A A A*. The circumference of the pallet is incomplete, from a portion being cut away to make room for the action of the teeth of the wheel; through the centre of this pallet *G* a steel axis passes, and is common to the large pallet *H H H*, the small pallet *o*, and the balance.

The impelling pallet *H H H* is supposed in the figure to be vibrating freely from *r* to *S*; here it is perfectly detached, or at liberty from the escapement wheel *A A A*, as will be seen by observing that the unlocking pallet *o* is not in contact with the discharging spring *N e*; nor are either of the teeth 3 or 4 of the wheel in contact with the impelling pallet. The balance or the impelling pallet (for they are both upon the same axis) vibrating from *r* to *S*, the discharging pallet *o* comes in contact with the discharging spring *N e*, (and from that instant it is not detached or free, but in the act of escaping,) and moving it in the direction from *e* to *d*, takes the locking pallet *a* from off the interior angle of the tooth 2, and sets the escapement wheel at liberty for the tooth 3 to act upon the angle *m* of the impelling pallet *H H H*. The tooth 2 will then have passed the locking piece *a*, and the tooth 1 will approach it. The tooth 3 pressing the impelling pallet from *r* to *S*, and continuing to do so until the angle *m* of the impelling pallet and the centre *G* of both pallets form a straight

line. The action of the wheel upon the pallet continuing until the point of the tooth 3 is about to quit the angle *m* of the impelling pallet, the tooth 2 approaches nearer to the circumference of the same pallet, and tooth 1 advances toward the locking piece or pallet *a*, against which it falls, and is held fast as soon as the end of the tooth 3 quits the impelling pallet. Here the act of escaping ends, and the impelling pallet is again detached or unconnected with the wheel, and moves in free vibration for a certain number of degrees, until it is returned by the power of the balance spring, and repasses from *S* to *r*, still independent of the escapement wheel, or of any thing else, except the very little resistance which is encountered by the discharging pallet *o*, in repassing the discharging spring *N e*, which it does without disturbing the locking piece *a*, or consequently the escapement wheel, and continuing for a certain number of degrees is again returned by the balance spring from *r* to *S*, when, resuming its situation as in the figure, it is prepared to act as before.

It may be proper to remark that the action of the cycloidal tooth upon the impelling pallet is always the same in the beginning, in the middle, and at the end of its motion, impelling the pallet with the same quantity of surface in action at all times, and at all times equidistant from the axis of the pallet.

(912.) *Earnshaw's escapement*.—The principle of this escapement, as we have before observed, is the same as in that just described; as, however, there exists considerable practical differences which are considered of considerable importance, we give, as in the former case, such parts of the author's description sent to the Board of Longitude as are necessary to point out the construction and action of the instrument.

A B C D, fig. 4, is the escapement wheel, and the small wheel *M S K* is the large pallet, which is a cylindrical piece of steel, having a notch or piece cut out of it at *l h r*; against the side of this notch is a square flat piece of ruby, or any hard stone *h l*, ground and polished very smooth, and fixed fast into the pallet. The cylinder is so placed with respect to the balance wheel that it may not be more than just clear of two adjoining teeth. *E F* is a long thin spring, which is made fast at one end by being pinned into a stud, and made to bear gently against the head of an adjusting screw *m*, the other end is bent a little into the form of a hook; to this spring there is fixed another very slender spring at *G*, which projects to a small distance beyond it. This small spring lies on the side of the thick spring nearest to the balance wheel. Upon the spring *E F* there is fixed a semi-cylindrical pin, which stands up perpendicular upon it, and of a sufficient length to fall between the teeth of the balance wheel *A B C D*. This pin is called the locking pallet, and is placed on the opposite side of the spring represented to view. Through the centre of the cylindrical pallet *M S K* a strong steel axis passes called the verge; the pallet is made fast to this axis, which also passes through the centre of the balance, and is made fast to it; it has two fine pivots at its extremities, upon which it turns very freely. A little above the cylindrical pallet *M S K* (as appears in the figure) is fixed a small cylindrical piece of steel *i n*, having a small part projecting out at *i*; this is called the lifting pallet: it fixes upon the verge like a collar, and is made fast by a twist, so as to be set in any position with respect to the large pallet *M S K*. The end of the long spring *E F* being made very

Mechanical
Processes.

Earnshaw's
escape-
ment.

Pl. lxiv.
Fig. 4.

Manufac-
tures.

slender, if a small force be applied at the point *o* to press that end out from the wheel *A B C D*, it easily yields in that direction, turning upon a centre at *G*; it is also made to slide in a groove in this stud, in such a manner that the end *o* may be placed at any required distance from the centre of the verge.

Having described the several parts as they appear in the figure, we next come to their connection or situation with respect to each other. Let the long spring *E F* be supposed to be placed so that the end of the slender spring *G i* may project a little way over the point of the lifting pallet *i n*, but not so close but that the point of the pallet may pass by the hooked end of the spring *E F* without touching it; the head of the adjusting screw *m* is also supposed to bear gently on the inner side of the spring *E F*, or that nearest to the wheel, and at the same time the locking pallet is so placed that one of the teeth *D* of the balance wheel may just take hold of it. This pallet is not visible in its proper place in the figure, being covered from sight by the screw *m* and part of the spring *E F*; its position is therefore represented by the dot *k*, on the opposite side of the wheel, having the tooth *A* just bearing up against it. From the above description of the several parts of the escapement, and their connection with each other, it will be easy to see the mode of its action, which is as follows:

A force being supposed to be applied to the balance wheel, so as to cause it to move round in the direction of the letters *A B C D*, one of the teeth, as *D*, will come up against the locking pallet, (as represented at *A*, and the locking pallet by *k*.) The wheel is then said to be locked, being prevented from moving forward by this pin. Let the balance be now supposed to rest in its quiescent position, and it will have the situation represented in the figure; the lifting point *i* of the pallet *i n* will be just clear of the projecting end of the slender spring, the face *h l* of the large pallet *M S K* will fall a little below the point of the tooth *B*, and remains perfectly at rest in this position. Now as the balance is carried a little way round in the direction of the letters *K M S*, by this motion the end *i* of the lifting pallet *i n* will be brought to press up against the projecting end of the slender spring, and as this spring is fixed on the side of the spring *E F* nearest to the balance wheel, the point *i* will press the two springs together out from the balance wheel; then, as only the point of the tooth *D* (see its position at *k*) touches the locking pallet when the spring *E F* was at rest against the head of the screw *m*, it will, by the spring being pressed out from the tooth, be now in the position *a*, clear of the tooth *A* of the balance wheel; the wheel being at liberty will move round by the force supposed to be applied to it; but as the point *i* of the large pallet moves on and presses out the spring, the point *l* approaches towards the point of the tooth *B* of the balance wheel, so that when the spring *E F* is sufficiently pushed out to unlock the wheel, the point *l* of the large pallet will be got to *d*, and in this position the point of the tooth *B* will fall upon it, and at the same time the point of the tooth *D* has just dropped off from the locking pallet *m*; the force of the wheel being by this means applied to the top of the pallet *h l* gives an increased momentum to the balance, and assists it in its motion in the same direction, and by the continued motion of the large pallet in the direction *M S K*, the point of the tooth *B*, which keeps pressing and urging it for-

ward, moves up towards the bottom of the face of the pallet towards *h*, until the plain flat surfaces of the tooth and pallet come into contact; by this time the end of the slender spring has dropped off from the point *i* of the lifting pallet, and the two springs have returned again into their quiescent positions, the spring *E F* gently bearing against the head of the adjusting screw *m*, and the locking pallet in a position to receive the next tooth *C* of the balance wheel. When the two surfaces of the tooth and pallet are thus in contact, the greatest force of the wheel is exerted upon the pallet, and of course upon the balance moving with it. The tooth still pressing against the face of the pallet, and the pallet moving in the direction *M S K*, it at last drops off, leaving the balance at perfect liberty to move on in the direction in which it was going. Just as the point of the tooth *B*, which has been pressing the large pallet round, is ready to leave it, the next tooth *C* of the wheel is almost in contact with the locking pallet *m*, so that the instant the tooth *B* drops off, the wheel is again locked, and the action of that tooth upon the balance is finished. As the balance moves with the greatest freedom upon its pivots, the force of the tooth has given it a considerable velocity, so that the balance still keeps moving on in the same direction; after the pressure of the tooth is removed by slipping off from the pallet, until the force of the pendulum spring being continually increased by being wound up overcomes the momentum of the balance, which, for an instant of time, is then stationary, but immediately returns by the action of the spring, which exerts a considerable force upon it in unwinding itself. As the balance returns, the point *i* of the lifting pallet *i n* passes by the ends of the two springs *E F* and *G i*, and, in passing by, pushes the projecting end *o* of the slender spring in towards the balance wheel, until it has passed it; which, as soon as it has done, the projecting end again returns and applies itself close to the hooked end of the spring *E F* as before. The spring *G i* is made so slender that it gives but little resistance to the balance during the time the point *i* of the lifting pallet is passing it, and of course causes but little (if any) decrease in its momentum. During the time the point *i* of the lifting pallet is passing the small spring, the long spring *E F* remains steadily bearing against the head of the adjusting screw *m*, as the hooked end just lets the end of the lifting pallet pass by without touching. As the spring has now been continually acting upon the balance from the extremity of its vibration in the direction *M S K*, it has given it the greatest velocity, when the point *i* of the lifting pallet is passing the end of the slender spring; for at this instant the spring, which was wound up by the contrary direction of the balance, is now unwound again, or in the same state as it was in its quiescent position at first, and of course has no effect upon the balance at all in either direction; but the balance having now all the velocity it could acquire from the unwinding of the spring, goes on in the direction *S M K*, until the force of this spring again stops it and brings it back again, moving in the same direction as at first with a considerable velocity. By this return of the balance, the point *i* of the lifting pallet comes up again to the projecting end *o* of the slender spring, pushes back the long spring *E F* and unlocks the wheel, and another tooth falling upon the face of the pallet *h l* gives fresh energy to the balance, and thus the action is carried on as before.

We have preferred entering at length upon the

Mechanical
Processes.

Manufac-
tures.

description of those escapements, which from their simplicity and perfect action are now universally adopted in box chronometers, to taking up the time of the reader unnecessarily in the description of the less important inventions, which, as clock and watch work has always been favourite subjects with the ingenious, are very numerous. The following are the list of the principal Works published in this Country and France; but we refer the reader for an extensive list containing the works of other nations to Gregory's *Mechanics*.

Authors on
clock and
watchwork.

(913.) *Horological Disquisitions*, by J. Smidt, London, 1694; *The Artificial Clockmaker*, by W. Derham, London, 1696; *Elements of Clock and Watch Work*, by Alexander Cummings, London, 1766.

An Introduction to the Mechanical Part of Clock and Watch Work, by T. Hatton, London, 1773; *Description of the Timekeeper invented by Mr. T. Mudge*, 1793.

An Account of the Going of Mr. Harrison's Watch at the Royal Observatory, by the Rev. Nevil Maskelyne, Astronomer Royal, 1767.

Remarks on the above, by Harrison.

Principles of Harrison's Timekeeper, with plates of the same, published by order of the Commissioners of Longitude, 1767.

A Description concerning such Mechanism as will afford a true Measurement of Time, by J. Harrison, 1775.

On the Going of Mr. Arnold's Chronometer, made on a new Construction, by D. N. Maskelyne, 1770.

Treatise on Clock and Watchmaking, by Thos. Reed, Edinburgh, 1826.

Transactions of the Royal Society.

Transactions of the Society of Arts.

Description Abrégée d'une Horloge d'une nouvelle Invention pour la juste Mesure du Temps en Mer, &c. &c., par Henry Sully, Paris, 1726.

L'Art de conduire et de régler les Pendules et les Montres, à l'usage de ceux qui n'ont aucune Connoissance d'Horlogerie, Paris, 1759. Fourth edition, by F. Berthould, Paris, 1811.

Traité général des Horloges, par le R. P. Dom. Jacques Alexander, Paris, 1734.

Règle artificielle du Temps, &c., par Henry Sully, Vienna, 1714. New edition by M. Julien le Roy, Paris, 1737.

Traité de l'Horlogerie, mécanique et pratique, approuvé par l'Académie Royale des Sciences, par Thiot l'aîné, Paris, 1741.

Essai sur l'Horlogerie, par Ferdinand Berthould, Paris, 1763.

Les Echappements à repos comparés aux Echappements à recueil, &c., par Jean Jodin, Paris, 1776.

Traité d'Horlogerie, par M. J. A. Lepante, Paris, 1767; *Traité des Horloges Marines*, par F. Berthould, Paris, 1770; *Eclaircissements sur l'Invention, la Théorie, la Construction, et les Epreuves des nouvelles Machines proposées en France pour la Détermination des Longitudes en Mer, &c.*, par M. F. Berthould, Paris, 1773.

Les Longitudes pour la Mesure du Temps, &c., par M. F. Berthould, 1775.

De la Mesure du Temps, &c., par M. F. Berthould, Paris, 1787.

Traité des Montres à Longitude, par M. F. Berthould, Paris, 1792.

Suite du Traité des Montres à Longitude, par M. F. Berthould, Paris, 1797.

De la Mesure du Temps par les Horloges dans l'Usage Civil, &c., par M. F. Berthould, Paris, 1797.

Histoire de la Mesure du Temps par les Horloges, par M. F. Berthould, Paris, 1802. Mechanical Processes.

Supplément au Traité des Montres à Longitude, par M. F. Berthould, Paris, 1807.

Horlogerie Pratique, par M. Vigniaux, Toulouse, 1788.

Essai sur les Montres aux Répétitions, par François Crespe, Geneva, 1804.

Cutlery and Hardware Manufacture.

(914.) The making of edge tools and cutting instruments, commonly denominated cutlery, a branch of the more general denomination of hardware, forms an important branch of English manufactures, but it is one less dependent on machinery than almost any other, and, therefore, does not fall so immediately within the province of the present Work. We cannot, however, allow it to be entirely passed over without notice. All the various sorts of cutting tools, as plane-irons, chisels, saws, knives, &c., require peculiar qualities, and are commonly separate branches of the cutler's trade; and the perfection of workmanship, tempering, &c., being the result of long and continued practice, could not be communicated in writing if even the parties were more disposed than they are to divulge their respective processes. We shall, therefore, attempt only a few general remarks.

Three different kinds of steel are used by cutlers, *i. e.* the blistered, shear, and cast steel. The first named is employed in the coarser and cheaper articles; the shear steel is used for all such edge tools as require great tenacity without much hardness, such as table knives, plane irons, scythes, &c.; cast steel is employed only in the manufacture of instruments requiring very fine edges, as surgeons' instruments, the better sort of razors, &c.

Historical Sketch of the Hardware Trade.

(915.) The following abstract from the Report of the Parliamentary Committee on the Hardware Trade will show its extraordinary increase during the last half century. Historical sketch.

Before the year 1780 there were probably fabricated in Sheffield nearly all the principal descriptions of goods which are now made, although of course in much more limited quantities. In the eighth edition, published in 1778, of the *Tour through the Island of Great Britain*, originally written by Defoe, we find the following account of the manufactures then carried on:—"The principal manufactures here are knives, forks, scissors, razors, lancets, phleams, files, edge-tools for carpenters, shears, &c., metal and horn buttons; and of late years various kinds of goods have been made plated with silver, such as knives, buttons, buckles, snuff-boxes, tweezer-cases, toothpick-cases, saucepans, coffee-pots, cups, tankards, candlesticks, &c. There is likewise reason to believe that here were first made snuff-boxes, candlesticks, &c., of a sort of coal called kennel, or channel-coal, formerly got near this place." Saws, indeed, the manufacture of which is now so important a branch, are not mentioned in this list of articles; but the omission is probably accidental. The amount of plated manufacture, both in Sheffield and Birmingham, had before this become so considerable that, in 1772, an

Manufactures.

Act of Parliament was passed appointing wardens and assay-masters for both towns.

The information on the subject of the present state of the manufactures and trade of Sheffield, to be found in the Report of the late Committee of the House of Commons, was principally obtained from two witnesses, Mr. Samuel Jackson, manufacturer of saws and steel, and exporter of hardware generally, and Mr. John Milner, who has spent the greater part of his life as a journeyman spring-knife cutler, but is now a manufacturer on his own account. This Report is of considerable length, and we avail ourselves of a very judicious abstract from it given in a useful statistical Work, published monthly, entitled *A Companion to the Newspaper*. It takes first a concise view of the present state of the hardware and cutlery manufactures in America and on the Continent, which we also give for the sake of the subsequent comparisons.

The declared value of the entire British and Irish produce and manufactures, exported to all parts of the world, is above thirty-six millions sterling; and in 1831, above nine millions, or about a fourth part of this sum, was the amount exported to the United States of America alone. Mr. Jackson states incidentally that one-fourth of the whole goods manufactured in Sheffield are exported to the United States. Considering the unquestionably large extent of the home consumption of Sheffield goods, we should think this a high estimate; but it appears from an account in the second volume of the Tables published by the Board of Trade, that of the whole British cutlery and hardware exported, the United States take rather more than one-half. The declared value of the whole quantity exported in 1832, was £1,433,297; of which the share of the United States was £738,015. Of the goods manufactured in Sheffield, indeed, there is but a very small portion exported to the Continent; the chief markets being in this Country and in America. Owing to the political agitation in the United States throughout the whole of the last year, (1833,) there was a great falling off both in the spring and in the autumn orders from that quarter; and Sheffield severely felt the effect of this suspension. We fear the new commercial difficulties which have resulted from the interference of the President with the National Bank must still for some time prevent the demand from rising to its former average. Mr. Milner says, "We are too much dependent upon the American market; should any thing unpleasant take place between America and England, we should be in a very bad state, for the experience of the last year and a half has shown the people of Sheffield, that if a convulsion took place in America, or if an alteration should take place in the commercial policy of America, Sheffield might be ruined." Fortunately, there is but little hazard of the occurrence of any one of the three calamitous events to which the apprehensions of the witness are directed. Of all insane wars that were ever undertaken, a war between two Countries, one of which, to mention no other bonds of union, is a customer to the other for not less than one-fourth of the whole amount of goods which that other annually has to dispose of, would assuredly be the most insane. The worst of the political agitation which has for some time interrupted the tranquillity and prosperity of the United States is also, it may be hoped, now over. And as for any alteration of the commercial policy of that Country, the only alteration which is now likely to take place is one that will be favourable to British inter-

rests, as involving a still further relaxation of the system by which the introduction of foreign manufactures has been hitherto attempted to be checked. Mr. Jackson, who has visited the United States, found some small manufactories of fine cutlery there; but owing, he says, to the high price of labour, they could not compete with the English. In consequence of the protection afforded by the former tariff, they had made some progress in the fabrication of some of the heavier kinds of edge-tools, and also in that of mill-saws, upon which a duty of one dollar each was paid, amounting to about fifty per cent. on the value; but their success was confined to these articles.

The declared value of the entire British hardware and cutlery exported, which in 1832, as already mentioned, was £1,433,297, was in 1831, £1,620,631. The difference was probably mainly produced by the falling off in the orders from America. The quantities exported in the two years were, in 1831, 16,799 tons, and in 1832, 15,294 tons. In the latter year the number of tons exported to each of the Countries, taking the largest quantities, was as under:

	Tons.
To United States of America ...	7874
British North America	1549
Asia	1032
British West Indies	667
Mexico and South America .	616
Germany	586
Foreign West Indies	560
Brazil	497
Italy	341
Africa	314

Smaller quantities were also sent to Russia, the Netherlands, France, Spain, and the Canaries, the Isles of Guernsey, Jersey, Alderney, and Man, Portugal, the Azores, and Madeira, Turkey and Continental Greece, Denmark, Gibraltar, Prussia, Malta, Norway, the Ionian Islands, Sweden, and the Morea and Greek Islands.

As to the continental manufactures, Mr. Jackson states, that in Prussia, Belgium, and France, a great many species of hardware trades are carried on, and several of them to a much greater extent than in Sheffield. Many are of recent origin, but others existed before there were similar manufactures in Sheffield. In repeated visits which he made to the Continent, this witness found the hardware manufactures constantly improving. The branches that appeared to be making the greatest progress were the scissors, saw, edged-tool, and steel manufactures; and the places in which these branches were carried on most successfully were the Duchy of De Berg in Prussia, Remschorld, Solingen, and that neighbourhood, and different parts of France. "In France especially," says Mr. Jackson, "many large manufactories have sprung up of late years, in consequence of the encouragement given to them by government, and by anonymous Societies with large capital, and they have been much protected in consequence of the prohibitory duties upon English manufactures." The operatives belonging to the French manufactories are described as very inferior to the operatives in England, in regard to both their comforts and their earnings. One of the greatest of the French manufactories is that at Molsheim, near Strasburg. "At this manufactory," says Mr. Jackson, "where they employ as many hands

Mechanical Processes.

Manufac-
tures.

in the manufacture of saws almost as they employ in Sheffield, the wages of labour are as twelve to one; that is to say, we have to pay for a single article as much as the manufacturer at Molsheim pays for a dozen. These observations were made by myself at the time of my last journey, (in the autumn of 1830.) Being a practical man, I took more interest in ascertaining the relative situation of the operatives in the two Countries. I will state, from the remarks I made, what I ascertained to be the usual terms of employment. A saw-grinder at Molsheim earns about 28 sous, or 1s. 2d. a day; he grinds and glazes six dozen billet webs, (that is a species of web of which large quantities are sent to America,) which makes the price 2½d. per dozen. The Sheffield price for the same work, not done in a superior manner, is 2s. 6d. per dozen." At this, which is the present rate of payment, the Sheffield workman would make from 15s. to 20s. per day. But wages were, some years ago, considerably higher; and "we have had workmen," says the witness, "that have earned 20s. on a Saturday morning before breakfast, when perhaps they had not worked the previous part of the week." This happened about 1810. A saw-maker at Molsheim, Mr. Jackson afterwards states, works in summer from five in the morning to seven in the evening; and in the winter from six in the morning to eight in the evening. The prices of provisions he found to be there as follows: household bread 1d. per pound; white bread 1½d. per pound; beef 3d. per pound; potatoes 2d. per peck; beer 1d. per pint. "In the Duchy of De Berg, in Prussia," he proceeds, "there is also a large manufactory of steel, saws, files, edged-tools, and cutlery; there are 800 saw manufacturers, 1000 file manufacturers, 3000 cutlers, 1000 sabre manufacturers, 1500 scissor manufacturers. A master saw manufacturer has generally three or four workmen who board and lodge in his house, and who receive, besides board and lodging, from 2s. to 2s. 6d. per week; without board and lodging, good workmen will obtain from 1s. 2d. to 1s. 3d. per day, and work from five in the morning till nine in the evening." These long hours, namely, from five in the morning till seven or nine in the evening, are stated to be general throughout the Continent; and the men, besides, appeared to Mr. Jackson to work much harder during that time than they do in England. There is very little intemperance among them. The prices of provisions in the Duchy of De Berg are, black bread, made of rye coarsely ground down, ½d. the English pound; white bread 1½d.; and meat 3½d. It is here that the articles are manufactured which principally come into competition with English goods in America. They cannot on the Continent make the circular saws, nor the hand saws, nor the back saws, nor long saws, so well as they can be made in England; but other kinds, including those which are chiefly in demand on the Continent, and in the American market, they can make fully as well as we can. The principal continental market where the French come into competition with us is that of Belgium. The people of that Country are supplied with certain kind of saws by the French manufacturers, and with other kinds by the English.

The finer descriptions of surgeons' instruments made at the manufactories of Paris, Mr. Jackson thinks inferior to those made in England, while the price is higher. "The reputation of English edged-tools," he says, "of files and saws, steel and razors, is very great throughout

France." English cutlery is occasionally smuggled into that Country through Belgium. It is believed, however, that of late years this had not been done to any considerable extent. With the exception of a pen-knife or a razor, there is little or no English cutlery to be seen in private families in France. The shops of the Palais Royal exhibit what they call English goods, but there is reason to believe that most of them are manufactured in the Country, and then impressed with the English marks, that they may bring a higher price. On the other hand, some of the finer articles of cutlery are occasionally brought from France to this Country; for example, scissors fitted with mother-of-pearl or ivory shanks, of which the workmanship is both cheaper and better than we can produce in England, although the blades are considered inferior.

As to the wages, and the comparative condition of the workmen in the two Countries, Mr. Jackson states the following facts: "The present price of provisions in France (in June 1833) is nearly the same as in England. A very intelligent French gentleman, who visited Sheffield last week, as the representative of a society just formed at Lyons, who are expecting to be large purchasers of foreign goods, gave me the price of provisions at Lyons and the neighbourhood at this moment; the price of bread, what is called *pain de menage*, is about 3 sous per pound; the price of meat from 10 to 12 sous. The cost of a house for a workman and his family—a house containing three rooms—would be from £5 to £6 per year, which is as nearly as possible the price at Sheffield. At Paris, the prices would be dearer." The wages in France vary from a franc and a half to three francs a day. In Sheffield, the operatives in the cutlery trade work eleven or twelve hours a day, and, in the different branches, were receiving in June last the following wages: of the spring-knife cutlers, the blade forgers from 21s. to 31s. 6d. per week; the workboard hands (those who put the knives together) from 15s. to 25s.; the grinders from 30s. to 40s.; of the table knife-cutlers, the forgers from 21s. to 35s.; the hafters from 18s. to 27s.; the grinders from 27s. to 40s.; of the razor-makers, the strikers from 24s. to 26s.; the hafters from 18s. to 40s.; and the grinders from 18s. to 50s. These were the wages for a full week of six days; but there might then be from 200 to 300 operatives not having more than two or three days work a week; and, of the whole number of operatives, probably not more than half were in full employment. The number of hands actually employed in each of the principal staple trades of Sheffield was as follows: makers of table-knives and forks, 3689; of pen and pocket-knives, 2680; of razors, 754; of scissors, 600; of files, 1768; of saws, 563; of edged-tools, 703; of stove-grate fenders, &c., 1530; of white metal articles, 643; and of silver-plated goods, 500; making a total of 13,430. There are, however, some other hardware manufactures carried on. The witness thinks that the workmen, at the present moment, owing to a variety of causes, do not receive the same amount of money for their work which they did thirty years ago; but still he is of opinion that their comforts are pretty much the same, and that they never either lived or dressed better than at present. "From what I have seen," he says, "of the manufacturers of England, I believe the workmen in Sheffield are better clothed and better fed, and live in better houses than the workmen in any other part of the country, or in any other part of

Mechanical
Processes.

Manufac-
tures.

the world." As to the French workmen, he represents them as miserable beyond description, as compared with the English. In certain branches of the business, too, which have been only recently introduced into France, he states that an English workman will produce more in a given space of time than a French workman. A good many British artisans have gone over to be employed in the continental manufactories, but most of them have very soon returned home. "In starting a fresh manufactory," says Mr. Jackson, "it is universally the practice, particularly in the iron trade, to employ a few Englishmen; but after their own workmen have obtained the same skill and knowledge which the Englishmen possess—the prices of English workmen being much higher than that of native workmen—it is of course the interest of the manufacturer either to expect the former to come down to the prices paid to the latter, or to let him return to his own Country. I am acquainted with Mr. Cockerill, a large manufacturer at Liege and Seraing, and when he commenced his manufactory, he employed a great number of English workmen, but I believe most of them have now returned to England. He had to pay for English workmen 7s. and 8s. a day, and his native workmen are employed at one and two francs a day."

Mr. Mil-
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Mr. Milner's evidence, although it does not perhaps contain any facts irreconcilable with the statements of Mr. Jackson, yet presents a more gloomy picture of the general condition of the workmen than that drawn by the latter gentleman. This witness says, that about 1817 a decline of prices began to take place, which has been going on ever since, and that from 1818 the circumstances of the workmen began to be sensibly operated upon. Employment has since been so irregular, that there never has been a sufficiency of it for more than a year or two at a time, and there has frequently been not half work for the entire number of hands. The destitution and misery of many of them on these occasions are described as being very great. Mr. Milner conceives that, upon the whole, the workmen now consume a great deal less than they did fifteen or sixteen years ago, both of such articles as tea, sugar, and coffee, and also of butcher's meat. Their dress he likewise thinks is much inferior to what it was formerly. It is evident, however, that, in judging of matters of this kind, people almost always proceed in great part upon mere general impressions, rather than upon a careful induction and sufficient examination of facts. There can be no doubt that wages have fallen considerably since the termination of the war, in the cutlery, as in all other trades; but it is by no means made out that the prices of provisions, and of the other necessities and comforts of life, have not declined in at least an equal degree. It is also beyond all question that the market for the hardware manufactures of this Country has of late years been greatly extended; and the quantity of employment upon the whole, therefore, must be much greater than it formerly was. We should think that this augmentation of the demand has fully kept pace even with the increase in the numbers of the workmen. Owing to circumstances, however, some of which at least are altogether beyond legislative control, the trade may not for the last twenty years have been so steady a one as it was for some time before; and, whether this may have been the case or not, of course, when a stagnation does take place, the number of sufferers is now greater, and the

sum of misery produced more frightful, than when the entire number of the persons connected with the business was only half or three-fourths of what it now is. A fact stated by Mr. Jackson should go a great way to prove that Mr. Milner's comparison of present with former times is to a great extent delusive. The poor-rates of the parish of Sheffield, it seems, in 1810 were £38,000, and now they do not amount to £20,000; a reduction which, even after making allowance for the rise in the value of money, cannot be regarded as less than fifteen or sixteen per cent. If we take it, as we ought to do, in connection with the increase of the population, (which since 1811 has risen from 53,000 to 92,000,) it is a real reduction of between fifty and sixty per cent. In other words, the pauperism of Sheffield is not now half so great as it was in 1810; yet at that time wages were higher than they have ever been since.

Mechanical
Processes.

Of late years, machinery has been introduced to some extent into the cutlery business in England, which has considerably reduced the cost of production in the case of certain articles. About ten or a dozen years ago, for instance, as Mr. Jackson states, to manufacture a three square file, it was necessary to forge it out of a square bar, but now, by the aid of machinery, the bar of steel is rolled three square. The witness found no rolling-mills for this purpose at the manufactories in the Duchy of De Berg. Of the different branches of the trade as carried on in Sheffield, the manufacture of scissors and that of plated goods appear to be in the greatest state of depression; or rather, they are the only branches that are depressed from any cause except the temporary diminution of the foreign demand. In the scissor trade, according to Mr. Milner, there were at one time between 300 and 400 forgers; and at present there are only about 170. To make up, however, for the falling off in the manufacture of wrought-steel scissors, there are now very large quantities of cast scissors manufactured in Sheffield. The latter is a very inferior article, but is so difficult to distinguish from the former by the eye, that cast scissors are often imposed upon the Public for those made of wrought steel. Mr. Milner is of opinion, and he says such is almost the universal impression, that the trade of Sheffield has been very much injured by the loss of reputation arising from this substitution of a spurious for a genuine article. Meetings have been held to devise some means of remedying the evil; and it has been proposed to incorporate the manufacturers of wrought-steel articles, and to allow them to stamp their goods with some common mark, which should be effectually protected; but no measures have as yet been taken to carry that plan into effect. Previously to 1814, it seems, no person could manufacture without taking out what is called an incorporated mark; but since that time, in consequence, as we understand the witness, of some change in the law, any person is allowed to use the mark of the Corporation of cutlers who chooses, and to place it on any description of goods he may find it convenient to manufacture. We may here mention, by the by, that of what is called town-trade, or London cutlery, there is, according to Mr. Jackson, very little really made in London. Notwithstanding the law to the contrary, he conceives it is not unusual even for the word London to be stamped upon many articles made at Sheffield. There may be some very fine and expensive cutlery made in the metropolis, but the greater part even of that description of articles must come

Manufac-
tures.

from Sheffield, from the greater cheapness of labour there. The witness mentions another fact connected with this matter. "Nearly all the Sheffield manufacturers," he says, "are obliged to strike the name of their customers upon their wares, and that is one reason perhaps why no cutlery manufacturers in Sheffield can keep stocks, as they are uncertain who their customers may be; and, as articles of hardware cannot be marked well after they are hardened, they are deterred from having a quantity made on hand till they have orders, to see what impression they are to bear." There appears to be no good reason why this inconvenient custom should be continued. As for plated goods, Mr. Jackson is of opinion, that people do not now buy as many articles of that description as they used to do; but the principal cause of the falling off in this branch of business at Sheffield appears to be, that it has partly migrated to Birmingham, where wages in some departments of it are only one half what they are at Sheffield. On the other hand, the file trade has nearly left Birmingham, in consequence of Sheffield having superior advantages for the manufacture of that article. Upon the whole, Mr. Jackson admits, what, indeed, must be considered quite indisputable, that cutlery is now consumed in this Country to as great an extent as it ever was; but the goods used, he says, are lower priced goods, and he seems to intend that we should understand goods of an inferior description. That more of such goods are now manufactured than formerly, we believe; but we believe, too, that the consumption of the better descriptions of goods also has increased, and that they, as well as the others, although no doubt at lower prices than formerly, are manufactured in greater quantities than ever.

That the hardware trade is upon the whole in a tolerably prosperous state, is proved by the admissions of the witnesses. The fall of prices in Sheffield goods since the Peace is asserted by Mr. Jackson to have been greater than from thirty to forty per cent.; but he also says, "If we may judge from the apparent circumstances of the manufacturers, there does not appear to be much more distress than there was formerly." It is acknowledged also, that the town has probably increased more than any other in England, both in population, and in the number of its manufacturing establishments. When asked if the manufacturers and merchants have been doing as well of late years as during the War, this witness answers, "We have had many merchants who have obtained very considerable property, though business is done at low profits." The trade for the last eighteen or twenty years has, it is stated, been carried on nearly all on orders; and, indeed, with the exception of a few remarkable years, there appears never to have been much of what is called speculation among the Sheffield manufacturers. It is said, accordingly, to have been ascertained, that there are fewer failures among them in proportion to their number, than among the manufacturers or merchants of any other part of England. Periods of depression in the hardware trade, indeed, appear to have occurred occasionally of late years, though not almost every second or third year, as Mr. Jackson loosely states. There was a great depression in 1816, and again in 1822; but since the latter of those years, although prices have generally been lower than they were previously to 1827, it is not pretended that there has been any stagnation till that occasioned by the late interruption of the usual demand from the United States. Mr. Jackson,

when asked if he would recommend a friend with capital in his pocket, and competent knowledge and industry, to embark in the Sheffield trade at present, replies, that the competition is so great that a person must have a perfect knowledge of the business in order to succeed in it; but when further asked if, should his friend have good capital in his pocket, he would rather recommend him to keep it there; his answer is, "I should think that most of the manufacturers fancy that they can employ their capital better in trade than by keeping it in their pocket." A manufacturer, he states also, who wishes to retire from business, can at present easily withdraw his capital. That is to say, the trade is in so fair a state, that more capital flows freely into it to replace whatever is taken out. Many of the branches of the hardware manufacture, however, may be carried on without much capital. There are some manufactories in Sheffield that have cost £30,000, or £40,000; but since 1817, according to Mr. Milner, a change has to a considerable extent taken place in the mode of conducting the trade, many persons having then commenced manufacturing without any capital, and their number having gone on increasing ever since, "so that now," as the witness assures us, "by far the greater portion of the cutlery business, and especially the spring-knife business, is conducted by men of this description."

Two witnesses connected with the business of brass-founding were examined by the Committee: Mr. John Dixon, of Wolverhampton, and Mr. Thomas Clutton Salt, of Birmingham. Their evidence extends over nearly thirty folio pages; and we can afford to notice only a few of the more important among the facts to which it refers. Indeed, by far the greater part of it is made up merely of strong expressions of belief and opinion, in support of which no well-ascertained facts are adduced. Both witnesses draw the picture of the existing state of the trade in the darkest colours. Both masters and workmen, according to their representations, are suffering to an extent which scarcely any former period has witnessed. Their favourite era of comparison, or rather of contrast, with the present times, we observe, is the years 1824 and 1825. Mr. Salt states that a capital of £10,000 then easily yielded him an annual profit of £3000. We submit that such returns as this could not be expected to continue. The truth accordingly appears to us clearly to be, that the depression under which the greater manufacturers are now suffering is merely the natural consequence and penalty of the extravagant trading of that former period. It is impossible to believe that the consumption of the articles of their manufacture has diminished, or the demand for them really fallen off within the last twenty years. No man can open his eyes and look around him without being convinced that this is not the case. We may mention merely lamps for domestic use, and gas burners and other fittings, as articles made wholly or partly of brass which must have created an almost entirely new demand within the period that has been mentioned. The witnesses admit that they cannot point out any instance of the least importance in which another material has of late years been generally substituted for brass. It is scarcely possible, therefore, to doubt that the manufacture of articles of brass is really now much more extensive than it was twenty years ago. It may be, however, that the quantity of goods annually made since 1825 has not since reached the amount to which it was carried in that and

Mechanical
Processes.

Mr. Dixon's
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Salt's evi-
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Manufac-
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the preceding year. The glut of the market then produced must in this, as well as in other businesses, have left a pressure which would continue to be felt for years. Accordingly, in order to meet this state of things, the aim of the manufacturer is now to reduce his stock as much as possible. Mr. Salt states, that he used to keep an average £6000 stock, but that now he never allows it to be above £1500. The efforts made with this object must, of course, have tended still further to reduce the annual production below what it was before 1825. But the change in the mode of managing the trade is in every way a beneficial one to the manufacturer. He is, in the first place, pursuing by far the best course for speedily relieving the market, and restoring the fair and full effect of the natural demand. And, secondly, while doing this, he is also unlocking a large amount of capital, and by that means carrying on his manufacture at much less cost than formerly. The prosperity of 1824 and 1825, however, when the brass founders were making an annual profit of thirty per cent. upon their invested capital, has likewise had the effect of attracting many new adventurers into the trade, and, by thus over-crowding it, opposed an additional difficulty in the way of its restoration to a healthy state. Both the witnesses speak of the numbers of persons formerly journeymen, who of late years have set up as manufacturers, and who, having little or no capital, and employing few hands, are either able, or are compelled by their necessities, to sell their goods at a lower price than that for which they can be produced by the larger establishments. Whatever is unsound, however, in this state of things, must also soon cure itself and pass away.

The fall in the prices of brass-foundry articles in the last fifteen years is, according to Mr. Dixon—who manufactures chiefly handles and the articles for plumbers, and not the finer descriptions of goods—more than 50 per cent. The nominal prices are indeed the same as they have been for twenty years; but, according to the practice of the trade, the sales are made always subject to certain discounts; and the discount which was formerly 20 per cent. is now 50. This fall, however, will not, as Mr. Dixon reckons, make a difference of 50 per cent. He says, correctly enough, "If we take 20 per cent. from 20s., it leaves 16s.; but if we take 50 per cent. it leaves us only 10s., consequently we have but 10s. instead of 16s." But it is not true that this, as he adds, makes more than 50 per cent. difference to the manufacturer. Taking the fact to be as stated, the manufacturer, where he formerly received 16s., now receives 10s., which implies only a fall of prices to the extent of not quite 38 per cent. The high prices referred to in this calculation are those that were obtained from 1819 to 1826.

To compensate this fall of prices, however, there has been a fall both of wages and of the price of the new materials. Of the latter, the principal is copper, which used to cost £112 per ton, and may now be purchased for £83. From this circumstance alone then we have a saving in the cost of production to the extent of 26 per cent. Lead also, another of the materials, which has been as high as £24, is now only £14 per ton; and spelter, which was £27, (a doubt is expressed if it was not a good deal higher,) now costs only £14 or £15. Mr. Salt complains of it as a disadvantage, that, whereas formerly it was the practice for the manufacturers in Birmingham to make all their purchases the first twelvemonth without paying any thing, and only to clear off

Mechanical
Processes.

the debt in the course of the second twelvemonth, they are now obliged to pay down cash for all the metal they require. But the change, while it has certainly introduced a wholesomer state of trade upon the whole, is really, in its direct and immediate operation, most beneficial to the manufacturer, who, for the long credit which he formerly enjoyed, used to pay no less than £1 per month on the ton; that is to say if he purchased a ton of copper at £112, and did not pay the money for a year after, it cost him actually £124. At present he gives his banker's bill for the metal, with only such a difference as may cover the discount.

The fall of wages since 1819 or 1820 is stated by Mr. Dixon to have been from 5 to 20 per cent. Wages now range from about 15s. to 25s. per week, and the average may be about 20s. Till 1825 it was about 27s. or 28s. This, by the by, would imply a fall of nearer 30 than 20 per cent. Afterwards the witness states, that to some of his men he still gives 35s. per week. They would have had two guineas before 1825. All this, however, is merely a calculation of what the men generally earn, or what they may earn; for they actually work by the job or piece, and not for weekly wages. The manufactory is opened at six in the morning, and they are allowed to work during what part of the day they please, till eight at night, when it is cleared, and the doors locked. Mr. Salt however states, that though he continues to pay the men who have been a long time with him from 24s. to 30s. a week, he gives no more than from 8s. to 11s. to his new hands; and he says he is sure he could in the course of a day get a 1000 men, all skilful artisans, to work for him at 6s. a week. Boys and women are now employed to do many parts of the work which the men used to execute. At Wolverhampton, also, it is stated, there are a vast number of females employed in the tin and japan trade, and in the screw trade. No machinery whatever has been introduced in the fabrication of such articles as those which Mr. Dixon furnishes; and that used in the department of the trade with which Mr. Salt is connected—the manufacture of lamps and ornamental brass-foundry in general—has not of late years been materially improved. It is well known, however, that owing to the introduction of steam as a moving power, even the old machinery now performs its functions much more economically than formerly. A remarkable instance of this is mentioned by Mr. Babbage in his *Work on the Economy of Machinery and Manufactures*. "Twenty years since a brass knob for the locks of doors was made at Birmingham; the price at that time being 13s. 4d. per dozen. The same article is now manufactured, having the same weight of metal, and an equal, or, in fact, a slightly superior finish, at 1s. 9½d. per dozen. One circumstance which has produced this economy in the manufacture is, that the lathe on which these knobs are finished is now turned by a steam-engine; so that the workman, relieved from that labour, can make them twenty times as fast as he did formerly."

(916.) *Processes followed in the cutlery manufacture.* Forging table knives.—The forging of the different articles depends a great deal on their size, and the purposes for which they are intended; some being worked by one man, others by two or more. Table knives are commonly forged by two men, one of which is called the maker or foreman, the other the striker. The blade of the knife is first rudely formed and cut off, it is then welded to a rod of iron about half an inch square, in such a manner as to

Manufac-
tures.

leave as little of the iron of the blade exposed as possible; from this a sufficient quantity is taken to form the bolster and tang; the former being shaped by means of a die and swage, and the latter by the hammer. This part being finished the blade is heated a second time, and is finished single handed on the anvil by the foreman. It is then again heated red hot and plunged perpendicularly into water to harden it; it is afterwards tempered at a blue colour, and is then fit for the grinder.

Table
forks.

Table forks are formed from rods of steel, which are about three-eighths of an inch square. The tang and shank of the fork are first roughly formed, and then cut off, leaving at one end about one inch of the square part of the steel. This part is afterwards drawn out flat to about the length of the prongs. The flank and tang are then heated, and a proper form given to them by means of a die and swage. The prongs are afterwards formed at one blow by means of a stamp, a machine which is very similar to that used in driving piles, but it is worked by one man; it consists of a large anvil fixed in a block of stone, nearly on a level with the ground. To this anvil are attached two rods of iron of considerable thickness fixed twelve inches asunder, perpendicularly to the anvil, and diagonally to each other, which are fastened to the ceiling. The hammer or stamp, about 100 pounds in weight, having a groove on each side corresponding to the angles of the upright rods, is made to slide freely through its limited range, being conducted by its two iron supporters. A rope is attached to the hammer, which goes over a pulley on the floor of the room above, and comes down to the person who works the stamp; two corresponding dies are attached, one to the hammer, and the other to the anvil. That part of the fork intended to form the prongs is heated to a white heat and placed in the lower die, and the hammer containing the other die is made to fall upon it from the height of about seven or eight feet. This forms the prongs and the middle part of the fork, leaving a very thin substance of steel between each prong, which is afterwards cut out with an appropriate fly-press. The forks are now annealed by surrounding a large mass of them with hot coals, so that the whole shall become red hot. The fire is then allowed gradually to die out, and the forks to cool without being disturbed, which process is intended to soften, and by that means to prepare them for filing. The inside of the prongs are then filed, after which they are bent into their proper form and hardened, which is effected by heating them red hot and plunging them into cold water; they are then tempered by exposing them to the degree of heat at which grease inflames.

Penknives.

The smaller blades, such as those of penknives, are forged by a single hand with the hammer and the anvil simply. The hammer in this trade is generally light, not exceeding three pounds and a half, the breadth of the face or the striking part being about an inch. The principal anvil is about five inches by ten upon the face, and is provided with a groove, into which a smaller anvil is wedged, the latter being about two inches square upon the face. The blade of the knife is first drawn out at the end of the rod of steel, and as much more is cut off with it as is thought necessary to form the joint, it is then taken in a pair of tongs, and heated a second time to finish the joint part, and at the same time to form a temporary tang for the purpose of driving into a small handle used by the grinder; another heat is taken to give the blade a proper finish, and the small

recess called the nail hold, used in opening the knife, is made while it is still hot by means of a chisel, which is round on one side and flat on the other. Mechanical
Processes.

Penknives are hardened by heating the blade red hot, and dipping them in water up to the shoulder; they are then tempered by laying them side by side, with the back downwards, upon a flat iron plate laid upon the fire, where they are allowed to remain till they are of a brown or purple colour.

The blades of pocket knives, and all that come under the denomination of spring knives, are made in the same way. Razors are forged by two men, similarly to table knives. The forging of scissors is performed by a single hand, and there is perhaps no branch of cutlery in which more taste is displayed than in the manufacture of the finer sort of these articles. The steel employed is here of course of the choicest quality, it must possess hardness and uniformity of texture, in order that the polish may be perfect, and great tenacity when hot to allow of forming the bow or ring of scissors, which requires to be extended from a solid piece having a hole previously punched through it. It ought also to be very tenacious when cold, to allow of that delicacy of form and work more frequently seen in the better sort of these articles. After the two parts of the scissors are formed as nearly to the same size as the eye can judge, they are properly paired and fitted by another workman with a file; the blades are also roughly ground, and the two sides adjusted to each other; after which, being bound together with wire, they are hardened up to the bows, and then tempered to a purple heat. The remaining part of the work is performed at the grinding mill with the stone, the glazer, and polisher, as described below. Scissors.

It would be useless to enumerate more at length the various articles which fall under the general term cutlery; they are all made by hand, more or less, on the plans already described, and having received their form and been properly tempered according to their intended purposes, are handed over to undergo the next process of grinding and sometimes polishing.

(917.) *Grinding.*—This is an important part of the cutler's Art, and is almost the only part in which machinery is employed, which, however, is very simple, consisting only of a drum which is driven either by horses or steam power; on this are several straps passing over pulleys fixed on the same axles as the grindstones, thus giving to the latter a proper circular motion. Different kinds of stones, and of different thickness and diameters, are required in the various parts of the grinding process, but they are generally so arranged as to have nearly the same circumferential velocity, viz., about 600 or 700 feet per second; this is effected by adjusting the size of the pulley to the size of the drum and stone. The men employed in grinding sit astride on a seat called a horse, so high as to enable them to reach over it. The larger and broader stones are used for grinding saws, fenders, and other articles exposing large flat surfaces. Table knives are ground on a firmly indurated sandstone, as are also penknives, the blades of common scissors, &c., but the finer kind of scissors are ground on a harder sort of stone, but of a similar composition, with water. Forks and the shanks of scissors are ground on a dry stone termed the fork stone; it is a very sharp grit of a whitish colour, very similar in its nature to mill-stone burr. Grinding,
glazing,
and polish-
ing.

The glazer and polisher are driven by the same machinery as the grindstones, but are made to move

Manufac-
tures.

with different velocities, the circumferential velocity of that of the former sometimes amounting to 1500 feet per second. This cylinder consists of a circular piece of wood, or rather of many pieces, so as to present their ends to the circumference; it is mounted on an axle the same as the stones, and its surface is covered with leather or sometimes with pewter; in the latter case these are called caps, in others, the wooden face is made use of. Some of the leather-faced glazers, such as are used for forks, table knives, &c., are first coated with a solution of glue and then covered with emery. Others, for finer purposes, are turned very true, and then their surface is indented with a sharp-edged hammer, and the interstices are filled up with a compound of tallow and emery.

The polisher is similar to the leather-faced glazer, being a cylinder of wood covered with buff leather, and the surface of which is supplied from time to time, while in use, with crocus, sometimes termed co-leather of vitriol. The velocity of this tool is much less than that of the grindstone, seldom exceeding seventy or eighty feet per second.

For general articles the operation concludes with the glazer, it being only those of cast steel to which the operation last described, which gives the most perfect polish, is applied.

Grinding
and setting
fine instru-
ments.

The grinding of the finer edged instruments is performed upon a grindstone of close grit, called a Bilson grindstone, and only water is used in the process. The face of the instrument is afterwards made finer by subsequent grinding on mahogany cylinders with emery of different degrees of fineness, or on cylinders faced with hard pewter, and the last polish is given on a cylinder covered with buff leather, to which crocus, or the red oxide of iron is applied with water. In the last operation care is required not to heat the work too much, as this would let down the temper of its edge, which is, of course, very thin.

The next operation is the setting, which in fine instruments, such as razors, surgeons' lancets, &c., is a work requiring great skill and delicacy of operation. The grinding leaves a ragged edge, which it is the first effect of whetting to reduce so thin that it may be bent backwards and forwards; this is called the wire, and if the whetting proceeds too far it would break off in pieces without regularity, leaving a finer, though still imperfect edge, and tending to produce accident while lying on the face of the stone. This wire is, therefore, removed by striking the edge against the stone while inclined at a proper angle, first on one side and then on the other, leaving thereby an edge formed by the inclination of the two sides of about 100° ; the edge thus formed is generally pretty even, but is, of course, too thick, and must be again reduced by whetting; a finer wire is by this means produced which will require to be again taken off, if for want of skill or delicacy of hand the workman should have carried the operation too far. The edge, however, at length thus far obtained, is completed by one or two slight strokes with the edge slanting foremost, the blade forming an angle of about 28° ; a measure which Mr. Stodart recommends as the one which, from long practice, he found to be the best for surgical instruments, razors, and other fine cutting edges. The excellence and uniformity of a fine edge may be ascertained by its operation when slightly drawn along the surface of the skin or leather, or other soft substance. Lancets are tried by dropping the point on

a piece of thin soft leather, when, if the edge be such as is required, it will not only pass with facility, but there will not be the least striking noise. This kind of edge is obtained by one or two strokes on a green hone.

Mechanical
Processes.

Such are the means commonly employed in setting razors and surgeons' instruments; but the following, from the known skill of its author, we have little doubt is superior and deserving the attention of cutlers. It is given by Thomas Andrew Knight, Esq. in the *Journal of the Royal Institution for 1830*. Mr. Knight observes: "In the preparation of steel, and in the art of subsequently forming it into cutting instruments, British manufactures are, I believe, unrivalled, but in the art of giving the finest possible edge to their instruments when formed, I think that they have generally something to learn." The author then proceeds to describe his apparatus. This consists of a cylindrical bar of cast steel three inches long without a handle, and about one-third of an inch in diameter, rendered as smooth as can be made with sand paper or glass paper applied longitudinally, and the bar thus made perfectly hard. Before it is used it is well cleaned, but made brightly polished; its surface is then smeared over with a mixture of oil and charcoal of wheat straw, which contains a portion of fine silicious earth.

In setting a razor the practice recommended is to bring its edge into contact with the surface of the bar at a greater or less, but always at a very acute, angle, by raising the back of the razor proportionably to the strength of the intended edge, and moving it in a succession of small circles from heel to point and back again without any pressure beyond that of the weight of the blade till the edge is obtained, which, if the razor has been properly ground, will be effected in a few seconds, and it may be renewed again subsequently by repeating the process without grinding. The edge thus obtained is remarkably smooth, very different from the serrated edge obtained by the usual strap, but it is said to be by no means indolent, and is, therefore, considered to be admirably suited to the purposes of surgical instruments; but as the bar is not calculated to give the best point, (as for a lancet,) a plain surface is made about a quarter of an inch square by grinding away one side of the bar, and on this the point may be obtained.

(918.) Besides the finished polish which renders the choicest kind of cutlery articles so extremely beautiful, they are sometimes also variously ornamented. Scissors in particular are not unfrequently decorated with studs of gold, silver, or polished steel; these are added by means of a small tang inserted into small holes drilled in the scissors, or the parts are inlaid with circular pieces of gold which are polished with the scissors, and are afterwards ornamented on the surface by engraving; they are also ornamented by means of gilding, blueing, and etching. The gilding is performed in two ways: first, by dipping the finished article into muriate of gold in alcohol; the second with metallic gold laid on by means of heat; the latter, however, requires too great a heat and commonly leaves the scissors too soft, and the other is not sufficiently permanent.

Ornamen-
tal work.

Other steel articles are also elegantly ornamented with coats of arms and various devices, particularly razors and swordblades, which is generally effected by etching. To perform this the device in question is carefully put on the polished article with a varnish made by dissolving resin in oil of turpentine, and every other part is covered with the same varnish except that

Manufac-
tures.

which is to form the ground of the picture. The exposed part is then covered with dilute nitric acid, which is suffered to remain upon it till it is supposed to be sufficiently corroded. It is then rinsed in water to wash away the acid, and the varnish is removed by means of oil of turpentine; when the ground of the figure appears of a dead white, the device itself and all the other parts of the article display their original polish.

Handling.

(919.) *Handling.*—Most cutting instruments, with the exception of scissors, shears, and a few others, require to have some kind of handle attached to them, which in the larger and coarser articles are commonly of wood cut to the most convenient shape according to their intended use, and are fixed to the instrument or tool in various ways, too numerous to admit of, and too simple to require explanation; but in the finer articles the handling requires some delicacy and exhibits great taste and elegance, as in the better sort of table knives and forks, penknives, razors, and surgical instruments, where the material employed is gold, silver, pearl, tortoiseshell, ivory, horn, &c.

Of table
knives and
forks.

The handle is secured to the blade in two ways; *viz.*, either by having a hole drilled in the material forming the handle a little larger than the tang of the knife, in which the latter is fixed by a strong cement, or the tang of the knife being made flat and thin, the handle, consisting of two side pieces called scales, is rivetted through the tang on each side. The former, however, is by far the more general method.

Those handles formed of gold or silver are thin metallic shells which are pressed into dies in two halves cut to the proper figure, decorated according to the taste of the manufacturer; these are afterwards soldered together, filled with a composition of rosin and pulverized brickdust which becomes exceedingly hard, and serves to give great firmness to the shell of metal, and, at the same time, to secure the blade.

Ivory handles are cut by hand out of larger pieces of the material as nearly as may be to the required form, they are then drilled by a drill in a foot lathe, reduced to their proper form by a file, after which they are smoothed down by a sort of burnisher, cutting a little on its edge, rubbed over with its own sawdust, chalk, and a little oil; they are then fixed upon the knife. All these operations, although performed by hand, are done with expedition on account of the acquired dexterity of the workman.

Horn handles are brought to their figure by pressure, the horn being first softened in hot water and applied in proper sized pieces in hot dies with a little oil. The dies or moulds are sunk in the two parts of a pair of tongs resembling a bullet mould, but of larger dimensions; they are then taken to the pressing vice, as we have described in button-making, but it differs somewhat in shape from the former, the jaws or pressing part being below. The horn being thus formed, if its colour is not good, is dyed of different colours, as green, black, &c.

Penknives.

Penknives being made to shut require more ingenuity in affixing the handle. The ornamental parts of penknife handles are generally ivory, tortoiseshell, mother of pearl, or stag horn, and the manner of attaching these is so obvious to inspection as to require little explanation; but the scales to which they are attached, the spring, &c. involve some difficulty and very nice workmanship. This part is commonly made of iron, although brass and silver are occasionally used;

the spring is always formed of steel; this serves to keep the scales at their proper distance, and its elasticity exerted on the tang of the blade secures the knife in its situation whether shut or open. These parts, that is the inner and outer scales, and the spring being first formed, are put into the hands of a workman who is employed to complete the handling.

Mechanical
Processes.

The tools consist of a vice, a small hammer and anvil, files, burnishers, a breast-plate, drill bow and drills of various kinds, a glazer coated with emery and glue to polish the different parts, and a buff similar to the glazer but used with oil, fine sand, and rotten stone, which latter is used for polishing the surface of the outer scales. The glazer and buff are turned by the foot in a similar manner to that adopted by the common street grinder. The workman is also provided with a number of hardened steel plates about a twelfth of an inch in thickness, and in shape corresponding to the different patterns of the handles by which the spring and blade are first secured in their places. Each of the inner scales is secured to one of the above plates for the sake of drilling holes through them opposite to the holes in the plate, the scales are then fastened on each side of the plate by temporary pins, and the edges filed down to the plate which ensure the handles being of the exact pattern and size. The spring is next drilled and placed between the scales, being secured in its proper place by temporary pins, and is then filed level with the edges of the scales. A hole is now drilled through the tang of the blade, one of the pins is taken out, the spring thrown back to allow the blade to be inserted where it is at first secured by a temporary pin, the tang is then filed square to correspond with the bolster or thicker part of the inner scale and the spring.

Every part being thus properly fitted and adjusted to some other, the temporary pins are removed, and all the visible parts which could not be touched with the file while the pins were in are now made smooth, the spring is bent gently a little inwards in order to increase its elasticity, and is then hardened and afterwards tempered at the spring temper; the outer and all visible parts are now burnished. The outer scales having in like manner been fitted, the whole are finally rivetted together and the knife is complete, except the last process of polishing the outer scales, the joint, and bolster, the former by scraping and buffing, and the latter by a file and burnisher.

The handling of razors is a very simple operation; the materials of which they are formed are brought to shape either by cutting or pressure according to the nature of it. A piece of white metal, an alloy of lead and tin, is placed between the scales at one end to allow the razor to go between them when the razor is shut, the blade is then screwed into its place and the scales are fastened together by means of rivets of iron, brass, zinc, or silver, according to the quality of the finished article, which completes the work, the polish and finish having been given to the scales themselves previously to this last operation.

Razors.

Founding.

(920.) Foundry or Founding is the art of manufacturing articles in cast metal; but the former term is very commonly employed to designate the building or workshop in which the casting of metals is carried on.

Founding.

The art of casting in metal among the Ancients was

Manufac-
tures.

so limited in its extent, from the little progress that had been then made in Metallurgy, that it may almost be ranked among the modern inventions, at least as regards its application to the Mechanical Arts, in which iron is almost alone employed. In fact, we are indebted for the immense extent and advantages of the use of casting to the facilities afforded to mining by the invention of the steam-engine, without which it could never have attained its present extent and importance.

Construc-
tion of a
foundry.

In constructing a foundry an important circumstance to be attended to is, that the foundation be well drained of water, as any dampness in the moulds is likely to produce the most fatal explosions by the sudden expansion of the steam: for this reason the floors of foundries are very commonly supported on pillars, or are at all events raised considerably above the ground. The most complete of these buildings are furnished with two or more air or reverberating furnaces, and two or three cupolas or small blast furnaces, the former of which are employed when a large quantity of metal is required, and the latter, which consist simply of a cast-iron cylinder lined with bricks, when only small quantities of metal are wanted, or more particularly when a charge is required in great haste.

The floor of a foundry should be formed of loamy sand, about ten feet deep, for the convenience of burying large moulds beneath the surface, so that the metal may be conveyed to them from the furnace by channels formed in the sand.

Different
kinds of
casting.

Casting may be divided into three branches, *dry sand*, *moist or green sand*, and *loam*, the first and second of which are executed in a similar manner from a wooden pattern in flasks; the only distinction being that the former is used for the finer description of articles, or when a more complete surface is required, and the latter in the larger description of articles intended to be painted, or when the appearance is not a consideration of importance. The loam casting is generally employed in cylindrical or circular articles, and the figure of the mould is given by a board of the shape of the centre revolving upon an axle instead of a wooden pattern.

By far the larger proportion of articles is executed in sand from wooden patterns, the making of which forms the distinct trade of the pattern maker, who must be a good workman as a carpenter, and at the same time he ought to be perfectly acquainted with the means and methods employed by the founder, so as to arrange the different parts of the pattern that the impression of the figure may be executed in sand in the readiest manner, a task which, in cases of complicated shaped figures, calls for a considerable degree of ingenuity and thought.

Pl. lxxv.
Fig. 1.

Flask casting.—To illustrate the simple flask casting, we have represented in plate lxxv. fig. 1, the manner of casting the beam of a steam-engine, the figure of which is such that every part tapers each way from the middle line, and, consequently, if it is imbedded up to this line it may be withdrawn without disturbing the sand. A B C D are the flasks, which have four handles, *a, b, c, d*, to lift them up by, and points or pins, *e, f, g, h, &c.*, which fit into corresponding holes in the lower flask, that they may be correctly placed in the same position after being separated. The under flask is set upon a board and filled with sand well rammed down; the workman then takes the pattern and presses it into the sand until it is immersed up to the middle line; he then smooths the sand up to the sides of the pattern by a trowel which is

represented in fig. 2. He next sets the empty flask over the other, putting the pins into the holes of the lower one, and after sprinkling some burnt sand over the lower flask to prevent the sand in the two from uniting, he places two or more cylindrical pieces of wood in the position where it is intended the metal is to be introduced; he then fills the upper one and rams it well down with the tool, fig. 11. The pieces of wood are now removed, leaving openings from the surface down to the pattern, and little holes are made in all directions from the pattern by a small iron rod, to allow of the escape of the air and the expansion of the steam from the moisture when the hot metal is introduced. The upper flask is now lifted off by men, or a crane if the casting is of large dimensions, and the pattern lifted out by inserting at each end a little instrument shown in fig. 3, having a screw at one end by which it takes a hold of the pattern, and a handle at the other to lift by. The upper flask is now again carefully placed in its original position, and weights being placed upon it to keep them together the mould is in a proper state for casting.

Mechanical
Processes.
Fig. 2, 3.

Fig. 11.

Fig. 4 represents the manner of casting a cog wheel with eight arms, all of which are ribbed on both sides. The pattern is laid upon a board with the face shown in the figure upwards; an empty flask is laid inverted over the board and pattern which is filled with sand and well rammed. A plain board is then laid upon the flask and two men turn it over, bringing the pattern to the top as shown in fig. 5: the workman with the small trowel then digs all the sand out of the space A A between each arm, leaving it level with the top of the ribs *a b c d*, and into each of the spaces thus formed a piece of iron plate, fig. 6, cut of the exact figure, is inserted, which

Casting a
cog wheel
described.
Fig. 4, 5.

Fig. 6.

has an iron rod *a* projecting from the upper side, and two points *b d* at the under side, which are inserted into the sand between the arms, so that the edges *e f* touch the upper edge of the arms *a b* of the wheel. The spaces above these plates are then filled with sand and rammed down level with the rest of the sand in the flask, and burnt sand sprinkled over the lower flask to prevent the sand, which is now to be rammed in the upper flask, from adhering to that in the lower; the holes for the metal are next made through the top flask, and it is then taken off, the iron plates and the sand upon them are taken out by the ends of the iron rod *a*, and the sand round the pattern being slightly wetted to cause it to adhere more strongly together, the cogs of the wheel, which are fixed to it by means of dovetail, are withdrawn separately. The whole wheel is then lifted out and the iron plates are returned to their original position, which is determined by the holes made by the points *b d* in the sand. The hole H through the wheel which is to receive the shaft is made solid in the pattern, and a projection of the same size as the intended hole, termed a *print*, is fixed on, which forms a recess in the sand shown at *k*; into this is placed the core shown in fig. 7, made of well-tempered clay or wet loam, afterwards dried, which extends between the opening of the flask and, of course, produces a hole of the required shape in the casting. The upper flask is now again put on, and weights being added it is ready for casting.

Fig. 7

In casting large cog wheels, flasks are often wanted as large as twenty feet square, wooden bars are then required to keep the sand from falling out, which extend across the flask, and have long nails driven into them, these flasks are lifted by a crane.

In the variety of shapes which are executed in cast

Manufac-
tures.

iron, many occur which will not draw in two ways from any one intermediate line; and in such cases the pattern is required to be made in two or more pieces which are fitted very accurately together by pins, and a greater number of flasks is made use of. With the aid of these various contrivances there are few shapes which the ingenuity of the founder does not contrive to execute in sand casting; but the variety of combinations of those made are so great, that it is impossible, with the limited extent of this article, to convey to the reader any thing more than a general idea of the principles upon which they are executed.

Loam
casting

Pl. lxxv.
Fig. 8.

(921.) We have now to explain the third description of casting termed the loam casting, which is generally employed for circular and cylindrical vessels. In plate lxxv. fig. 8, is given the section of the mould for the cylinder of a steam-engine, which will sufficiently illustrate the manner of conducting this description of casting. A A is an iron frame, placed upon wheels for the purpose of being conveniently moved to any part of the foundry, in the centre of which is fixed a cylindrical tube or cylinder B B. C C is a ring of iron, with four ears of flanches for the purpose of lifting it, which is placed upon the frame as near as possible concentric with the cylindrical tube B B. Upon this ring a thickness of sand is first placed, and upon the sand a cylinder of brickwork is constructed, the interior diameter of which exceeds by a few inches the exterior diameter of the intended cylinder. A rod D D, provided with arms E E, is now placed in the cylindrical tube, and to these arms is bolted a mould of wood of the exact shape of the intended cylinder, which being revolved upon its centre D D forms upon the loam covering the internal surface of the brickwork the exact impression of the shape of the cylinder. The whole mould is then removed to an oven to be baked, and in the mean time, by a similar operation, a core of brickwork, covered with loam, is made of the size of the interior of the cylinder, the only difference in the operation being that the wooden pattern which gives the shape is placed on the exterior instead of the interior of the cylinder.

Fig. 9.

This has also to be rendered perfectly dry by baking. A pit is now dug in a convenient part of the foundry, of sufficient depth to contain the mould, into which it is lowered by a crane, and the apparatus shown in fig. 9 is used for slinging it to the crane. A B C D E is a wrought-iron cross, the arms of which are made sufficiently strong, or are strengthened by ties; on each of the four cross bars a ring with a hook is loosely fitted, from which ropes or chains extend to the flanches or ears before described in the bottom plate C C, and in this way, by sliding the hooks nearer or further from the cross, the mould may be made to hang vertically. When the mould and core are in this way let down into the pit and properly adjusted, the sand is thrown and rammed down about half the height; a flat cover of dried loam is then put on the top of the mould and core, and round pieces of wood are put into the holes which had before been made in the cover for pouring in the metal; the burying of the mould is then completed, and the sticks which keep open the holes for the metal being pulled out and small ditches made from the furnace to them, every thing is ready for casting.

Origin of
the Art.

(922.) *Casting statues.*—The casting of statues is one of the Arts which was practised and attained great perfection among the Ancients; but its first invention appears to have been at so remote a period that little is

known respecting it. The methods that were subsequently made use of by the Greeks and Romans appear also to be unknown; for notwithstanding the taste for statues which was at that time carried to such a pitch as to lead to the proverb that in Rome the people of brass were as numerous as the Roman people, it suddenly died away, no record of the process being preserved; and it was but little practised among the Moderns until the commencement of the XVIIth Century, since which time it has, however, again arrived at a considerable state of perfection.

Mechanical
Processes.

The first operation in the common method of casting statues is to form the inner mould or core, which is, in fact, a rude resemblance of the figure intended to be cast, but made smaller in all its dimensions; it is composed generally of potter's clay mixed with horse's dung and hair, or of plaster of Paris with fine brick-dust, and is strengthened with ribs of iron so as to enable it to maintain its figure. The rough core thus formed is covered with wax of such thickness that the dimensions of the figure may be in excess of that intended to be executed; and it is now in a fit state for the hand of the sculptor, who operates upon it in the same manner as if executing a statue in any other material.

Common
method of
casting
statues.

This part of the process is, however, sometimes different, inasmuch as the wax is formed on a model, and afterwards disposed and arranged on the core which is formed as the sculptor advances with the figure.

When by either of the above methods the core is completed, little tubes of wax are fixed perpendicularly to the surface from top to bottom, which serve both as jets for the conveyance of the metal to all parts of the work, and as vent-holes to give passage to the air, which would otherwise occasion great disorder when expanded by the heat of the fluid metal. This is now covered over with a coat or crust termed the shell, which being put on in a soft or semifluid state takes the impression of the different parts which it afterwards communicates to the metal. The material of which the shell is composed is varied accordingly as different layers or strata are applied; the first is a composition of clay and old white crucibles well ground and sifted and mixed up with water to the consistency of a colour fit for painting, which is applied with a pencil, laying it seven or eight times over and letting it dry in the intervals; for the second strata, horse's dung and earth are added to the composition; and the third, which is of considerable thickness, is composed simply of horse's dung and earth. The shell is now secured and strengthened by several bands or girts of iron wound round at about six inches distance from each other, and fastened at top to a circular ring, and at bottom to a grate upon which the statue is erected.

If the figure to be cast be of such dimensions that the mould in the state above described is too weighty to be removed to the furnace, the erection of it must be executed on the spot. A square hole is made in the ground near the furnace where the metal is to be melted, of sufficient dimensions to contain the mould, the sides of which are lined with freestone or brick. At the bottom of this is a hole of smaller dimensions covered over by the grate upon which the figure is erected, and contains a furnace to dry the mould and melt the wax. When the figure is complete, a moderate fire is lighted in the small furnace and the hole covered over with planks, which confines and equalizes the heat, and causes the wax to run swiftly down from all parts of the figure out of the pipes introduced for the purpose, at the

Manufactures,

foot of the mould, but which are carefully closed with earth as soon as all the wax is carried off.

The hole is now filled all round with bricks thrown in at random, and the fire in the furnace is increased until such time as the bricks and the mould become red hot, which ordinarily happens in twenty-four hours; it is then extinguished, and when every thing is cold again, the bricks are taken out and the space is filled up with earth well rammed in order to make the mould and firm steady.

Nothing now remains but to melt the metal and run it into the mould. The furnace resembles an oven in construction, and has three apertures, one to put in the wood, another for a vent, and a third to run the metal out at. From this aperture, which is kept closed while the metal is in fusion, a little tube or canal is laid by which the melted metal is conveyed to a large earthen basin situated over the mould; into this basin all the branches of the jets or casts which convey the metal to the different parts of the mould are inserted. All the jets are terminated or stopped with plugs which are kept close until sufficient metal is contained in the basin to supply the whole figure; they are then speedily removed by iron rods attached to them, and the melted metal rushes into and fills up all the cavities which had been previously occupied by the wax. The figure is now complete as far as the casting is concerned, but has still to pass again through the hands of the sculptor, who removes the jets and repairs any parts in which the casting is imperfect.

In the casting of statues of great dimensions, the quantity of metal employed forms a large item in the expense, and has led to the invention of methods of forming the moulds by which the thickness of metal can be more correctly adjusted to the required strength of the different parts than in the one above described, where such a thickness of wax is added as is necessary to complete the figure, and which of course is liable to be much greater than is required for absolute strength.

Valvasor's method of casting statues.

(923.) A method of casting statues very thin was invented by John Weichard Valvasor of Carniola, which with some slight variations has been applied of late years on the Continent with considerable success. The following is the author's description of the invention given in the sixteenth volume of the *Philosophical Transactions*.

"First, I form out of good clay that will endure the fire, and not crack either in drying or burning, any figure or statue desired; when this is well dried, I make all over the figure small holes of no great depth, but both in size and depth proportioned to the size of the statue; into these holes I put small pieces of metal, and with some of the same clay fix them firmly in the holes: the use of these bits of metal, marked in fig. 10, plate lxxv., *a a a*, &c., is to keep the core and mould from touching each other, or falling together when the wax runs out, and that they may remain constantly in the same fixed position. This done, I scrape away with some proper instrument as much of the clay in thickness as I design for the thickness of the statue; and laying it in a furnace the core or first clay statue is burned till it is red hot. When cold, the core is rubbed all over with a sort of earth or colour used by German potters to colour the joints of the tiles when they set stoves of tiles. This colour resembles black lead, and, being mixed with water, it is daubed all over the core because the metal is found to run freely upon it. This done, I lay upon the core as much yellow wax mixed

VOL. VIII.

with pitch or rosin as will make the thickness of the intended statue, which I form in the wax with all the exactness possible.

Mechanical Processes.

"Next, I put all over the surface of this statue of wax little pieces of wax termed the little channels *c c c*, all of them so contrived as to enter into the channels *d d d*, &c. This done, I cover the core and wax all over with the same sort of clay that will endure the fire without cracking, and thus the concave statue or mould is made. Upon this are laid the great channels *d d d*, both upright and transverse, formed likewise in wax and placed according to judgment, so as best to receive the ends of the little channels *c c*, &c., for the easier distribution of the metal.

"The great channels must all meet at the top of the statue so as to come out by one hole at *e*, where the metal is to be poured in; it is also necessary to have a channel or two to let out the air as the metal enters, as those marked *f f*; and there must be a hole or two left at the foot as *g g*, where the great channels and waxen statue join, and at which, when the mould is burned, the wax both of the statue and of the channels may run out. The great channels being thus placed, the mould must be again laid over with the same sort of clay, and when this mould is well dried, I heat the whole red hot.

"The mould being thus burned, I stop with the same clay the two holes *g g*, and then bury it in a pit, and proceed as is usual in casting of bells and the like; but care must be taken that the metal be very well melted. If it be a small statue not above a foot or two high whose mould may be managed in the hands, then I make a concave statue of wax of the thickness desired, and place upon it all the great and small channels as before, which done, I put it all together into a liquid substance, made of plaster and tile or brick-dust tempered with water.

"If the statue be intended very thin, I take copper, and when it is well melted, I mix with it a good quantity of zinc, the more the better the metal runs. I have sometimes for small and thin statues put in above a third part of zinc, and I have found by experience that this mineral makes the metal run more freely, and gives it a fair golden colour.

"The statue being cast, I take off the mould and cut off the channels, all which, both great and small, are filled with metal, which may be kept for further use; in these there is much more metal than in the whole statue, for if the statue be very thin, there must be more and larger channels; and so the cheaper the statue the more weighty the channels, and the more metal remains.

"To know the quantity of metal requisite for my intended work, I take a lump of the same mixture of wax and pitch with which I make the mould of my statue; and having weighed it I make a mould upon it, and cast in the same a lump of metal of the same size, which I weigh, and thereby compute the proportion of the weight of the metal and wax, and thus knowing the number of pounds of wax I use about the figure and channels, I can calculate nearly how much metal I should melt."

(924.) The method employed in casting the fine statue of Lord Hopetown, erected in Edinburgh in 1834, very much resembled that above described. In consequence of the unusually large dimensions of the figure, the sculptor, Mr. Campbell of Edinburgh, obtained permission of Government to have the use of the foundry in

Statue of Lord Hopetown.

Manufac-
tures.

the Royal Arsenal at Woolwich, where the author of the present Essay had frequent opportunities of inspecting it. The work was executed by Frenchmen, and the methods being entirely novel in this Country excited considerable interest; we trust, therefore, the following short description may not be uninteresting.

The figure is first made in plaster of Paris, of the exact shape and dimensions it is intended to be when completed in metal, and placed in an erect position on a firm platform. It is now covered all over by a shell, composed of a number of pieces fitted very correctly together, so that they may be removed and built up in another situation, forming in the interior a figure exactly resembling the original one in plaster. The work is commenced at the bottom, by covering with strong sand such part as is intended to form one block of the shell, to about an inch or an inch and a half in thickness, to which is added about one foot in thickness of plaster of Paris, which unites with the sand and forms one block; the remaining part of the figure is completed up to this height all round, in a similar manner by blocks, of which the number and arrangement must be such that they may be removed when the shell is complete without disturbing the sand. Another course is now commenced and completed in the same way, and the work is thus continued until the whole figure is completely surrounded by the shell. During the progress of the work, tubes are cast in with the plaster for the admission of the metal and for the escape of the air, as in the common method, and iron rings are let into the plaster for the convenience of raising and removing the blocks. When the shell is complete, it is taken to pieces and removed to the casting pit, where it is carefully rebuilt, and the interior filled up with the material to form the core. It is now a second time taken to pieces, leaving the core of the exact shape and dimensions of the original figure, from which is scraped off such a quantity of material as will give the necessary thickness of metal to each part of the figure. The shell is then again put together in its original position, and will, therefore, leave a space between the interior of it and the core exactly equal to the thickness of material which has been removed. Nothing now remains to be done but drying the mould and running off the metal, which operation is performed in the same way as in common figure casting.

This ingenious method of casting is the means of saving a great weight of metal, and from that cause consequently diminishes the expense; but it calls for so much greater degree of labour, that it is doubtful whether it will prove economical in this Country.

(925.) *Casting bells.*—The methods employed in casting bells does not differ materially from that which we have described as the common mode for statues, the thickness of metal being formed upon the core in wax, which is afterwards removed by melting.

A hole is first dug of a sufficient depth to contain the mould of the first bell, which must be wide enough to admit a free passage between the mould and walls of the hole, or between each mould and the walls if several bells are to be cast. At the centre of each intended mould a stake is driven very firmly into the ground which supports an iron peg, on which turns the pivot of the compasses used in the construction of the bell. The stake is encompassed at the lower end with solid brickwork termed the millstone, which serves as a foundation for the construction of the core. The core is constructed of bricks with intermediate courses of plain

earth and is solid except a small opening in the centre to contain coals for baking the core. The brickwork is rather less than the intended diameter of the core, and the remaining part is completed with a layer of cement made of earth and hog's dung, to which the exact interior shape of the bell is given by the compasses; it has, however, to be observed, that this cannot be done at one operation, as the shrinking of the core by baking materially alters the figure; the operation has in consequence to be repeated several times, the core being thoroughly dried between each operation.

The internal core being completed, a thickness equal to the intended thickness of the metal of the bell is removed from the compasses which are now of the shape of the interior of the shell or exterior of the bell. The material forming the interval between the core and the shell is composed in the part next the core of earth and hair, and the outer part of a mixture of wax and grease, which contains any coats of arms, inscriptions, &c., that may be intended to be executed on the bell.

Upon this surface the shell of the bell is constructed in different layers; the first of which is composed of the same earth sifted very fine and mixed with cow's hair, and a sufficient quantity of water to reduce it to a fluid state, which is poured over the surface of the wax and penetrates into all the sinuosities of the figures. When this layer is thoroughly dried, it is covered a second time with the same matter, but somewhat thicker. After this the wax is melted out, and the shell is completed by layers of earth mixed with cow's hair and hemp.

The ear of the bell requires a separate work, which is done during the drying of the several incrustations of the cement. It has seven rings, of which the seventh is called the bridge and unites the others, being a perpendicular support to strengthen the curves. It has an aperture at the top to admit a large iron peg bent at bottom, which is introduced into two holes in the beam, and fastened with two strong iron keys. Models are made of the rings with masses of beaten earth dried on the fire, which are gently pressed upon a layer of earth and cow's hair one half of its depth, and then taken out without breaking the mould. This operation is repeated for each of the twelve half moulds, two of which united form the hollows of six rings and the hollow of the bridge.

Upon the open space originally left for the coals are placed the rings which constitute the ear. The iron ring to support the clapper of the bell is first placed in this aperture, and the diameter of the thickness of the core is made up by a round lump of clay, which after baking is clapped upon the opening and secured with thin mortar, which binds the cover close to the core.

When every thing is in its proper place, the outside of the hollows of the rings are strengthened with mortar, in order to bind them with the bridge and keep them steady at the bottom, they are then left to dry that they may be removed without breaking. The whole shell is now raised from the core, the part composing the thickness of the metal is broken and removed, and the shell, previously smoked by burning straw under it to smooth the surface of the bell, is placed in its original position; an interval being of course left between the shell and the core equal to the space occupied by the earth, hair, and wax, into which is run the metal from a furnace, situated near the hole containing the mould, of a similar construction to that employed in casting statues.

Mechanical
Processes.

Casting
bells.

Manu-
factures.

Cannon
foundry.

The metal is however different, containing one-fifth part of tin, whereas that for statues is composed entirely of copper and zinc.

(926.) *Casting guns.*—The guns employed in the ordnance are of two kinds, *viz.*, iron and brass, the former metal being used in the larger description of guns, such as ship-mortars, ship and battery guns, carronades, &c., and the latter for the lighter pieces used in the field.

The iron guns which are supplied to Government by contract are cast in sand from a wooden pattern, in the common manner of sand casting; but in the brass guns, all of which are executed in the foundry of the Royal Arsenal at Woolwich, a totally different method is employed, which therefore requires a more particular description. The manner of preparing the mould will be understood by the following description. A wooden cylinder is made to revolve in bearings near its extremity, and is made of a taper figure to facilitate its being withdrawn; upon this cylinder the core or pattern for forming the mould is made in the following manner. A band of straw is first wound round from one end to the other, of such a thickness that the cylinder becomes nearly of the size of the intended gun; the band is now covered over with a composition of loam and dung, and a pattern formed in wood edged with iron, of the exact shape of the intended gun, is pressed against it, while a workman with the aid of handles turns the round core, and causes it to take the impression of the shape of the gun. The core is now dried by means of a charcoal fire lighted in the pit, and a fresh quantity of the composition is added to such parts as are found imperfect, and the pattern or mould is again applied. It is then again dried, and if any parts are found imperfect, or if the dimensions do not agree with the drawing given by the superintendent, the operation must be repeated as many times as may be necessary to render it quite correct.

By this process all the cylindrical parts of the gun, from the breech to the muzzle, are formed, as also a cylindrical part extending beyond the muzzle, the object of which is to consolidate the metal of the gun and render it of a more equal density; this part, after the gun is cast, is of course removed. The trunnions, dolphins, and such parts as are not cylindrical, have now to be added; the trunnions are made of the same composition of loam, &c., and are fastened to the gun by means of iron pins; but the dolphins and all other ornamental parts are formed in wax, which is afterwards melted away. The core being thus complete is covered over with loam mixed with water, at first in a fluid state, and in thin layers, and afterwards with thicker layers of less fluid matter, until it is covered with a thickness of material equal to the projection of the trunnions above the gun, so that they are on a level with the exterior surface of the mould. The mould when dry is secured with iron hoops, and the interior core is removed by blows on the smaller end of the taper cylinder, which soon loosens it and permits its being withdrawn; the workman now seizes the end of the straw band and pulls it gently out, and by that means so completely breaks and destroys the loam composition, that it can be readily removed without any difficulty, leaving a perfect impression of the cylindrical parts of the gun in the interior of the mould; heat is then applied, which melts out the wax used for the ornamental parts, and the mould of that part of the gun extending from the breech to the muzzle is complete and ready for casting.

The mould for the breech of the gun, which is made

in a separate piece, is executed in a similar manner in loam, by revolving it in bearings against a pattern of the required figure. The exterior of the mould is in this case also turned to a particular figure to fit a cast-iron step, which is firmly bedded at the bottom of the hole in which the gun is to be cast, and which serves as a foundation for the mould. When the mould for the breech of the gun is prepared as above, and dried ready for casting, it is placed in its step in the hole in front of the furnace, and the earth filled in all round it to make it quite firm and steady; the mould of the body of the gun is now placed in its position exactly over it, and the ground is filled up to the top, when nothing further remains to be done but running the metal from the furnace, which being of the ordinary construction requires no particular description.

The alloy for brass guns is made at two operations, as follows:

The tin is first converted into what is called hard metal or alloy, 75 parts copper and 25 parts tin, for the purpose of preventing its escape in vapour, which would take place to some extent if thrown into the furnace alone.

The copper is then melted and brought to the proper state for casting, at which time the above alloy is introduced and the whole well stirred together.

Gun metal is composed of 12 pounds tin to 112 pounds copper, or 46 pounds alloy, as above, to 76 pounds copper.

(927.) *Casting lead pipes.*—Until of late years, the greater portion of the leaden pipes used in water-works was made of sheet lead wrapped round an iron or wooden core, and the joint soldered up; but the expense of this method being considerable, and the pipes thus made being extremely liable to burst at the joint, suggested the idea of casting them, by which the labour of previously casting and laminating the lead into sheets would be spared, and also the uncertainty of the soldered joints. Such pipes are cast in an iron mould made in two halves, forming when put together a hollow cylinder of the size of the intended pipe; a core or iron rod is adapted to this mould, which is secured by screws or wedges, so that it exactly occupies the centre of the hollow mould, leaving therefore an equal space all round, and a spout or entry for the admission of the melted lead is made by a corresponding notch cut in each half of the mould, and at another place a similar vent for the escape of the air. This mould is fixed down upon a long bench, and a rack moved by toothed wheels and pinions is fitted at one end of it, in a line with the centre of the mould, which, by a hook inserted into an eye at the end of the core of the mould, affords the means of drawing out the core when the pipe is cast. The halves of the mould are then separated and the pipe is moved along, so that only an inch or two of its end remains in the mould, the halves of which are again fastened together with the core between them, and its end entered an inch or two into the first piece of pipe. The mould is now filled with melted lead, the heat of which fuses and unites it with the end of the first piece so as to double its length, and the core again drawn out is ready for adding another piece. In this way any length of pipes may be cast, but the metal is liable to have air-bubbles in it, which produce holes where the metal is thin; besides which the joinings of the different lengths are not always perfectly sound.

Another method, therefore, which is now very generally adopted, is to cast the lead in an iron mould, upon a cylindrical rod of the size of the bore of the intended pipe,

Mechanical
Processes.

Proportions
used in gun
metal.

Casting
lead pipes

Manufac-
tures.

the space left for the metal being three or four times the thickness of the intended pipe, and in short lengths, which are then drawn through holes in pieces of steel in the manner of wiredrawing till the metal is reduced to the intended thickness and length. Another method is to reduce the pipe by repeatedly passing it through the two rollers of a flattening mill, in each of which a number of semicircular grooves are formed all round, so that the two rollers when united have circular cavities between them, which gradually diminish in diameter from one end of the rollers to the other. The pipe is first rolled between the largest of these cavities, then in a smaller, and so on to the last, which extends it to its proper length and diminishes its substance to the thickness required, at the same time by condensing the metal hardens it, and makes it very strong. Mr. John Wilkinson of Brosely, the celebrated iron manufacturer, took out a Patent in 1790 for the above method which he practised on a very extensive scale; he appears, however, not to have been the original inventor, the same thing having been proposed in 1728 by Mr. Fayolle. See *Machines approuvées par l'Académie Royale*, vol. v. p. 50. Since the expiration of this Patent, many manufactories of this article have been established, some employing rollers, and others the draw-bench for extending the pipes.

Apparatus
for drawing
lead pipes.
Pl. lxvi.
Fig. 7, 8.

(928.) *Apparatus for drawing lead pipes.*—In plate lxvi., fig. 7, 8, we have given sections of the mould for casting the pipes, with an elevation of the apparatus connected with it.

a a is the bench which is supported on legs in an inclined position, and *b b* are the two halves of the mould fitted into each other with double rebates (as shown in the section, fig. 8) that they may come together correctly, and *d d* are screws fitted through pieces of iron attached to the bench, by which they are secured in their position when thus united; the halves of the mould are made flat at each end on the under side, and rest upon the iron plate connecting the two pieces *e e*. *f* is the core which is held in its position by collars at each end of the mould, and *g h i* is the rack and wheelwork for drawing it out. The intention of the inclined position of the mould is that the metal which runs in at the lower end by the entry *c* may expel the air as it rises at a vent in the upper extremity, in the position marked *v* in the drawing, by which the danger of air-bubbles is entirely avoided. Attention must be paid that the interior surface of the mould is bored out truly cylindrical as well as to the core being turned in a lathe, that they may be certain, when united, to leave an equal space all round; a circumstance which is essential to forming a good pipe, as the succeeding process of drawing will tend to make an error of this kind worse. The core *f* has a neck or smaller part at the end *d*, as seen in fig. 8, and the treble or core *a g*, fig. 9, upon which the pipe is to be drawn, is of the same size and has a smaller neck, so that the pipe when put upon it fits in every part, and the shoulder of the neck prevents it being drawn through the pipe in the direction from *g* to *a*, being inserted in the opposite direction. Beyond the neck the treble has a notch cut in each side at *g*, which is seized by a sort of claw of the machine employed for drawing the tube, an elevation of which is shown in fig. 10 of the plate. The framework of the machine is composed of two strong timbers *A A*, which are firmly secured at one end to uprights *B B*, and at the other to a cross beam *C*. *D* is a cog wheel put in motion by a water wheel or steam-engine, on

Fig. 10.

the shaft of which is a drum or roller *E*, which is free to revolve on the shaft, but can be put in connection with it when required by the handles and levers *F F*. The drum *E* has a pair of spiral grooves formed on its circumference for the reception of two chains, the ends of which are hooked to a carriage *c* running upon two wheels, and provided in the hinder part with a fork or double claw to engage the notches at the end of the treble *T*. *C* is a cast-iron frame securely bolted down to the cross beam *C*, which has a notch in the upright side nearest the roller, to allow the treble and pipe to pass through, but at the same time forms a lodgement for the steel plate through which the pipe is to be drawn. The workmen are provided with a great number of these plates which are termed whistles, one of which is shown in fig. 11. The holes in the whistles are made rounding at each side as shown in the section, fig. 12, to facilitate the exit and entry of the pipe, and diminish very gradually from the size of the rough-cast pipe to that to which it is intended to be reduced.

The process of drawing is as follows: the lead pipe being fitted upon the treble is laid upon the rollers in the bench, and the end of the treble being put through the largest of the set of whistles, its end is hooked into the claws in the carriage *c*, and the whistle lodged against the cheeks of the frame *G*. The drum is now put in gear with the wheelwork by the levers *F F*, which winds up the double chains and draws the pipe through the whistle, by which it diminishes its size and lengthens it out. When the pipe is drawn completely through, the roller is cast off by returning the levers *F F*, the treble is unhooked from the carriage and pushed back into its former position, and a smaller whistle being put on, the pipe is drawn through as before, and the operation is in this way repeated using smaller whistles each time, until the pipe is rendered of the required length and thickness. Sometimes the pipe is drawn through as many as twelve whistles, in which case, for the second and eleventh time a whistle is employed, of the section shown in fig. 13, which having a sharp edge, cuts off a shaving from the surface of the lead making it perfectly smooth and true, and causes it also to pass more easily through the succeeding whistles.

Lead pipes are by these processes drawn out to ten or twelve feet length, three of which are united into one by an operation termed *burning*. An iron core is put through one pipe and entered a few inches in the other, and a small iron mould is put together in two halves over the ends of the two pipes which are brought in contact, the mould exactly fitting both. Melted lead is now poured into the mould which runs out again at a hole in the bottom, until it is supposed the heat of the lead has fused the ends of both the pipes, when the hole in the bottom is stopped by a slider adapted to the purpose, and the mould remains full and forms when cold a union of the pipes, which is perfectly good if the pipe remains straight, but is liable to leak if a bend is made at one of them.

In the year 1804 a Patent was granted to Mr. Alderson, for a mode of manufacturing lead pipes lined with tin, for the conveyance of beer, water, or other fluids, which were in danger of receiving an injurious taint from the corrosion of the lead. The method consisted in first casting a lead pipe in the manner above described, withdrawing the core and throwing into the pipe a small quantity of powdered rosin, and then inserting a core rather smaller in diameter than the first.

Alderson's
Patent.

Fig. 10, 11,
12, 13.

Manufactures.

The pipe was then placed in a vertical position, and the core being placed concentric with it so that an equal space was left all round, melted tin was poured in, which as it rose in the pipe melted the rosin which acted as a flux to unite the two metals. This pipe was then lengthened out by rolling or drawing in the manner above described.

Bramah's Patent.

Mr. Bramah also invented a very ingenious mode of manufacturing lead pipes, for which he took out a Patent, which consisted in pumping or forcing the metal in a fluid state into the moulds. A boiler or kettle is fitted up over a fire-grate with flues for the fusion of the metal, in the centre of which a force-pump is fixed, provided with a suction valve to draw in the melted lead from the boiler; the forcing pipe proceeded through the side of the boiler and conducted the lead to the mould, which consisted of a tube bored perfectly smooth and cylindrical, its interior diameter being equal to the outside of the pipe intended to be made. The end of the mould nearest the boiler was expanded in a conical mouth of larger diameter than the mould, and across this a bar was fixed to support the mandril of a diameter equal to the bore of the intended pipe, which was situated exactly in the centre of the mould, leaving an equal space all round, and was made slightly conical. The mould was situated in one of the flues surrounding the boiler that the lead might be preserved in a fluid state to within a short distance of the end, which was immersed in a cistern of hot water; by this means, when the force-pump was in action, the lead remained melted until it arrived at the extremity, which it quitted in the form of the manufactured pipe, and could thus be made of any length required. This method, although very ingenious, we believe, produced pipes more liable to fracture than the other above described, and has not for that reason been much adopted.

Type founding. Pl. lxvi. Fig. 1, 2, 3.

(929.) *Casting letters or types.*—In plate lxvi., fig. 1, 2, is given a perspective view of the upper and lower half of a mould employed for this purpose, which, when united, (as shown by the dotted lines in fig. 2,) form a space or mould to receive the metal, on which the letter is to be formed. A A is termed the carriage of the mould, and corresponds with the part B in the opposite half, and is fitted to it by the projections and corresponding recesses C C, G G, termed the male and female gauges. The upper part of the mould E is termed the *pallet*, and inclines each way from the body so that when the two halves are united a space is left resembling the figure of the frustum of a pyramid. The pallets and body are cast in one piece, and are attached by the plate *a a* to a piece of wood *b b*, which serves to give bulk to the mould and render it more convenient to handle, and at the same time, from its being a bad conductor of heat, prevents the heat, which the mould acquires after being used for some time, from incommoding the workman. The remaining parts of the mould, *viz.*, *f*, which is termed the *nick*, F I the register, (see also fig. B,) *g g* the stool, and *h h* the *spring* or *bow*, (shown broken in the figure,) will be better understood when we describe the operation of casting. The part by which the impression of the letter is given, termed the matrix, is shown at H in the figure, and separately in fig. 3. It is composed of brass or copper, and is about one inch and a half long, and of a thickness in proportion to the size of the letter it is to contain, which is impressed upon it by means of a punch.

The metal of which the letters are made is generally prepared in large quantities and cast in bars of about

twenty pounds weight, which are delivered out to the workmen as they may be required. The furnace for the purpose, which is built under cover, is provided with a revolving vent in order that an equal degree of heat may be given to every part of the vessel in which the metal is melted, which is of cast iron, and contains, when full, several hundred weight of metal. When the fire is heated, the bars of lead are let down gently into the pot, and the fusion is promoted by adding a quantity of pitch and tallow; the flame thus produced is drawn very fiercely into a flue situated about a foot beyond the furthest lid of the pot, which makes it act very powerfully in melting the lead, and at the same time assists in conveying away the fumes, &c. from the workman to whom this laborious part of the business is committed. When the lead is thoroughly melted, a due proportion of the regulus of antimony and other ingredients are put in, and more tallow is inflamed to make the whole incorporate sooner. The workman now, having mixed the contents of the pot very thoroughly by stirring them with an iron ladle, draws off the metal into small troughs of cast iron, which are ranged to the number of eighty or a hundred upon a level platform faced with stone.

In the course of the day fifteen hundred weight of metal can be prepared in this manner; and the operation is continued for as many days as are necessary to prepare a stock of metal of all the various degrees of hardness.

Before the founder commences his work, he melts a quantity of the metal, prepared as above, in a furnace of smaller dimensions, and provides himself with a ladle which will hold a quantity proportional to the size of the type intended to be cast. He then attaches a thin piece of leather to the matrix, fig. 3, by means of a string wound round the little groove *ee*, and after putting the two halves of the mould together, and placing the matrix in the matrix cheek, he attaches the other end of the leather to the wood of the upper half mould by rosin, so that after they are separated to deposit the type, and reconnected, the matrix will assume its correct position by simply pressing it into the cheek.

Fig. 3.

He now takes the under half of the mould in his left hand, embracing the wood part between his thumb and three fingers, and places the upper half of the mould upon it so that the pin gauges may fall into the recess gauges; he then clasps his left-hand thumb over the upper half of the mould and quickly catches hold of the bow or string at the top of it with his right-hand fingers which he presses against a notch at the back of the matrix; at the same time with his hinder fingers he draws the under half of the mould towards the ball of his thumb that both the registers of the mould may press against both sides of the matrix, while his thumb and fingers press both halves of the mould close together.

He now takes the ladle, which is placed full of metal at the hole of the furnace, in his right hand, and applying the jet of it to the mouth of the mould, pours in the melted metal, at the same moment he tilts the mould forwards, or, as it is technically termed, receives the metal with a strong shake, which causes it to pass more rapidly without cooling to the face of the matrix, and consequently to take a more perfect impression. The workman then separates the mould by placing his right-hand thumb on one end of the wood, and his two middle fingers on the other, and throws the letter upon a sheet of paper laid for that purpose on the bench, and is then ready to cast another letter as before.

Mechanical Processes.

Manufac-
tures.

When the foundrymen have got a certain number of types boys come and break off the jets, fig. A, which they throw into the pots and carry the type in parcels to other boys who polish the broad sides upon smooth, flat stones. This is a very dexterous operation and is a remarkable instance of what may be effected by the power of habit and long practice; for these boys in turning up the other side of the type do it so quickly by a mere touch of the fingers of the left hand, as not to require the least perceptible intermission in the motion of the right hand upon the stone. The types thus finely smoothed and flattened on the broad sides are next carried to a third set of boys who sit at a square table, two on each side, and who arrange them on long rules or sticks fitted with a projection to prevent them from sliding off, which are placed upon a set of wooden pins fixed into the wall in order to undergo the finishing operation.

This requires a workman of considerable experience and skill: he takes one of the rules and, with a peculiar address, slides the whole column of types upon an instrument termed the dressing-stick, which is made of well-seasoned mahogany, and furnished with two end pieces of steel, one of which is movable and can be made to approach the other by means of a long screw-pin inserted in the end of the stick. The types are placed on this instrument with their faces next the back or projection, and after being adjusted so as to stand even, they are made fast by the screw before described; the whole, if requisite accuracy is given to the moulds, assuming the appearance of one solid, contiguous plate of metal. In this position the workman smooths the narrow edges which could not be done on the stone, by scraping the surface of the column with a thick edged but sharp razor, until the whole becomes one plane, and he afterwards turns them over and completes the other edges in the same manner. The next operation is that of bearding or barbing, which is effected by running a plane, faced with steel, along the shoulder of the body next the face, which takes more or less off the corner as occasion may require; and this being completed nothing now remains to be done but the grooving, which is a very material operation, as the superfluous metal of the jets which still remains on the types would make them bear very unequally against the paper while under the printing press, and effectually mar the impression. The grooving operation consists in removing this superfluous metal, and in making a groove that the bearing of every type may be regulated by the shoulders imparted to them from the mould; this is done in the following manner. The types being screwed up in the stick as before mentioned with the jet end outermost, and projecting beyond the wood about an eighth of an inch, the stick is put into an open press, and every thing being made fast by a long wedge which bears upon a slip of wood lying along the length of the types, a plough or plane, made of polished iron, is applied, which is so constructed as to embrace the projecting part of the types between its sides, and which in one or two applications removes all the superfluous metal of the jet, and, by means of a steel cutter bearing between the shoulders, forms a similar groove on the head of each of the types. The types being now finished are removed from the press and examined by turning the faces to the light to perceive any imperfect or damaged letters, which being removed the remainder are complete and ready for sale.

(930.) *Casting stereotype.*—This method of printing by casting in an impression taken from the movable type in plaster of Paris, although a modern invention, has arrived at a great state of perfection, and is now becoming adopted in all Works for which there is a large demand, or those of which the demand is continued long after the first publication. Mechanical Processes.
Stereotype founding.

The introduction, progress, and the more particular application of this important invention are given under PRINTING; we propose at present simply to describe the processes of casting as performed in the most improved printing-offices of London.

After the type has been set up, as in the usual manner of printing, and carefully examined and corrected, a single page is placed in the lower part of a moulding frame A A, represented in plate lxvi., fig. 4, and wedged up tight by wedges *a a a*. The upper part of the frame B B, which is somewhat larger than the page, is placed over the lower frame, resting upon the wooden wedges, and determines the dimensions of the mould, the plaster being filled into this up to the level of the rim. After the upper frame is adjusted in its position, the types are rubbed with an oily composition to prevent the plaster of Paris adhering to the face of the type which would of course render the mould imperfect; but to prevent this effect entirely, considerable care is required not only in covering the type in every part with this oily substance, but in the preparation of the plaster and in the separation of it from the page.

The plaster when first applied is in a very fluid state, and is poured very evenly over the surface; more is then added until the frame is filled up level with the rim, and the plaster having by this time become much thicker, in a very short time the whole is perfectly set and may be removed from the page. The workman then examines it, and if found to be perfect, it is trimmed round the edges with a knife, and several notches being cut in the margin to allow the metal to enter the mould, it is fit for baking; a process which also requires a great deal of care and experience, as any irregularity of the heat of the oven would cause the moulds to warp.

In fig. 5 of plate lxvi. is given a perspective view of the casting box, in which the metal impression from the plaster mould is taken in the following manner. The mould, when sufficiently baked, is removed from the oven and placed upon a movable plate of cast iron, situated at the bottom of the pot (termed the footing plate) with its face downwards, and upon the back of the mould rests the cover of the casting box, the inside face of which, as well as that of the floating plate, are made perfectly accurate. The cover being held firmly down by means of a screw *a* and shackles *b b*, the whole is lowered by a crane into a boiler or pot containing the melted metal, which enters through the openings *c c c c*, at the four corners of the box, and insinuates itself between the floating plate and the mould, forcing against the under surface of the mould with a degree of pressure which causes it to enter every sinuosity.

After having remained immersed for about ten minutes, it is steadily lifted out by the crane and swung to a cooling trough by which the under side of the box is exposed to water; and when thus cooled the workman proceeds to remove the mould, which with the new formed type and floating plate forms one congealed mass. After the superfluous metal and plaster are removed the stereotype comes out bright and well formed, but is yet imperfect, as the proper thickness

Manufactures.

cannot be determined by the mould alone, but each plate has afterwards to be reduced to an equal thickness by a lathe in which the plate revolves against a cutting tool, which moves along the face by means of screws.

The edges of the plate are then trimmed, and it passes into the hands of a workman, termed the *picker*, to undergo the finishing operation, which consists in minutely examining every part of the plate and removing the small globules of metal which occasionally fill up such letters as the *a* or *e*, inserting new letters if any should be broken, or, which is a more delicate operation, removing with a graver any impurities which may fill up the lines of wood-cuts, which are executed in the same manner as the types and form part of the plate.

Gold Beating.

Gold beating.

(931.) The origin of this Art is not known, but it seems to be of some antiquity. It is mentioned by Homer, but from a description by Pliny of Roman gilding, the thinness of the leaf bore no comparison with that of the modern gold beater, one ounce of gold forming only 750 leaves four fingers square, whereas the thinnest gold leaf of French manufacture does not exceed the 480,000th part of an inch, that of the English being about the 300,000th part. This refinement in the Art is, therefore, comparatively modern, and is very interesting, not on account of any machinery or any extraordinary skill which it calls into action, but for the extreme point of reduction thus obtained, and the practical illustration it affords of the great divisibility of matter and the ductility of the precious metals, particularly of gold; for although silver leaf and even brass leaf are obtained, the thickness is not reduced to the same extent as in the case of gold.

Preparation of the metal.

The gold in preparation for beating is melted in a black-lead pot or crucible with borax in a wind furnace, and as soon as it is in perfect fusion it is poured into an iron ingot mould six or eight inches long, three-quarters of an inch wide, previously greased and heated so as to make the grease run and smoke, but not so as to flame. When the gold is fixed and solid it is made red hot to burn off the unctuous matter, and then forged into a long plate, which is further extended by passing it between polished steel rollers till it becomes no thicker than a ribbon or a sheet of paper. The plate or ribbon, as it is called, is carefully divided by compasses, and cut by shears into equal square pieces; each of these pieces are again worked by hammer on the anvil till it is one inch square, and are then annealed to correct the rigidity acquired by the forging and flattening mill, each piece weighing about six grains, and therefore in this state being about $\frac{1}{750}$ th of an inch in thickness, 150 of them weighing two ounces, the quantity commonly operated on at a time.

These are now to be extended by beating; and to effect this it is necessary to interpose some smooth body between them and the hammer for the purpose of softening the blow and defending the gold from its immediate action, as also to place between every two of the plates some intermediate substance, which, while it prevents their uniting together, may suffer them to extend freely; these objects are attained by means of certain animal membranes. These are of three kinds, and used for different purposes: first, the outside cover is commonly parchment made of sheep skin; secondly, for interlaying with the gold in the early state of the

process, they use fine vellum made of calf's skin; and thirdly, for the latter part of the operation, the fine skin of ox-gut slit open and prepared for this purpose only, and hence called gold beater's skin.

Mechanical Processes.

(932.) *Process of beating.*—The bed on which the beating takes place is a smooth block of black marble weighing from 300 to 600 weight, about nine inches square on the upper surface, fitted into a wooden frame two feet square, so that the frame and marble surface are one level, the back and both sides are furnished with a high ledge, and the front, which is open, has a leather flap fastened to it which the gold beater uses as an apron for preserving the fragments of the gold which may fall off. The only tools are three hammers having round and somewhat convex faces: the first or heaviest, called the *cutch* hammer, is about four inches in diameter, and weighs about fifteen pounds; the second is called the *shoddering* hammer, weighs about twelve pounds, having the same diameter; and the third, still nearly of the same diameter, weighs about ten pounds. The square pieces of gold plate (150 in number) above mentioned are interlaid with leaves of vellum about three or four inches square, one leaf being laid between every two, and about twenty more leaves are laid on the outsides, over these is drawn a parchment case open at both ends, and over this another in a contrary direction, so that the vellum and plates of gold are kept tight and close. The whole is then beaten with the heaviest of the three hammers till the gold is extended to the breadth of the vellum, the pieces are then taken out of this case, are each cut in four with a steel knife, and the 600 pieces thus produced are interlaid in the same manner with pieces of the ox-gut skin. The beating is then repeated with a lighter hammer till the gold has acquired the extent of the skin, when they are again divided into four pieces each by a piece of cane brought to an edge. The whole number of leaves is then divided into four parcels which are interlaid as before, and beaten separately till they are stretched, for the third time, to the breadth of the skins. After this last beating the leaves are taken up by the end of a cane instrument, and being thrown flat on a leathern cushion are cut to a size one by one with a square frame of cane made to a proper edge, or a frame of wood edged with cane. They are then placed in small books between twenty-five leaves which are well smoothed and rubbed over with red bole to prevent sticking. In this state they are sent into the market.

Description of apparatus.

Process of beating.

It may be proper here to observe, that the gold used for this purpose is never pure, because pure gold is too ductile to be worked between the gold beater's skin; the finest gold for the purpose has three grains of alloy in the ounce, and the coarsest twelve grains, but in general the alloy is about six grains to the ounce or one-eighth part. The alloy is silver or copper or both, and the colour produced is of various tints accordingly. Two ounces two pennyweights of gold are delivered by the master to the workman who, if skilful, will return 2000 leaves or eighty books, together with one ounce six pennyweights of cuttings.

The leaves being 3.3 inches square on the side, it may be shown that each leaf averages $\frac{1}{25000}$ th part of an inch in thickness; but the French, who carry the process further than the English, are said to reduce the thickness to the $\frac{1}{40000}$ th part of an inch.

The process of gold beating is very much influenced by the weather: in wet seasons the skins become damp, which renders the process tedious; the best workings

Manufac-
tures.

are in fine weather and with new skins, the latter losing their smoothness after being once or twice used, but will last through six or eight beatings.

We have seen that the gold beater cannot mix a superabundant quantity of alloy with the gold without destroying its ductility, but a means has been devised of producing what is called party gold leaf, the basis of which is silver, and which has only a superficial coat of gold on one side. This is done by placing a thick leaf of silver and a much thinner one of gold upon each other, which being heated and pressed together unite and cohere, and this being submitted to a process in every respect similar to the one above described, the gold, though in quantity only about one-fourth of that of the silver, is found every where to cover it, the extension of the latter keeping pace with that of the former.

Gold Wire Drawing.

Gold wire
drawing.

(933.) What is called gold wire is, in fact, only gilt wire, at least there is very little actual gold wire made, and that only for one purpose, filigree work. The common gold wire is made by covering a silver rod of about an inch thick, two feet in length, and weighing about twenty pounds, with a coating of gold, and then reducing it into wire by drawing. The purity of the gold employed for this purpose is a matter of great importance, as on this depends the beauty and durability of colour when wrought into laces, brocades, &c. The fineness of the silver is of less consequence, it is indeed better when alloyed, being too soft in its natural state for this work. The gold is employed in thick leaves made for the purpose, which are applied all over the silver rod and pressed down hard upon it with a burnisher, more or less of the gold leaves being laid over each other according to the intended quality of the wire. The smallest quantity of gold allowed is 100 grains to a pound of silver, and the largest quantity seldom exceeds 140 grains.

First pro-
cess.

The beginning of the process as well as the preparation of the material is performed by the refiner who uses pieces of hardened steel with a piece of tough iron welded on the back to prevent the steel from breaking; in this back part holes are made considerably larger than the corresponding ones in the steel and of a conical shape, partly that the rod may not be scratched against the outer edge, and partly for receiving some bee's wax which allows the rod to pass more freely, and preserves the gold from being rubbed off. This end being properly secured in a strong frame and the end of the bolt reduced so as to pass through the hole, this end of the bolt is seized by a pair of strong pincers whose jaws are cut somewhat like a file to prevent the rod from slipping out by the violence necessary for drawing the bolt through, the branches or handles of the instrument are bent upwards and a loop put over the curvature, so that the force which draws them horizontally serves at the same time to press them together. A sufficient power being now employed the bar is drawn through, reduced in diameter and extended in length; the same process is repeated with smaller holes till the original bar has been reduced to about one-fourth or one-fifth of an inch in diameter, in which state it is sent from the refiner to the wiredrawer.

Drawing
plates.

In reducing the coil of wire from the size above stated, a particular kind of plate is employed principally received from France; it is a metallic mass, its principal

part being iron. There are two sorts of these plates, one of considerable thickness for the wire in its largest state, the other only about half as thick for the smaller wire where less force is required. These plates, although in some degree brittle, have sufficient toughness to admit of the holes being beaten up or contracted by a few blows with a hammer, so that when any of them have been widened by the wire passing through they may be reduced again, the hole after each beating being opened by a long slender instrument made of the finest steel, one end of which, to the length of about five inches, is round and serves as a handle, the rest, about twice as long, is square and tapered to a fine point. The first holes being so far worn as to be unfit for bearing further reduction, the next of them, become likewise wider, supply their place, and are themselves supplied by the succeeding ones to the end, one hole in each plate thus, of course, becoming useless. Great accuracy and dexterity is required in adapting the hole to the wire that the latter may not pass too easily nor so stiffly as to endanger its breaking. For determining this point with the greater accuracy, the workman uses an instrument called a *size*, consisting of a brass plate on which is measured, by means of notches cut at one end, the increase which a certain length of wire should gain in passing through a fresh hole, and if the wire is found to stretch too little or too much, the hole is contracted or widened accordingly. There are also other instruments for measuring the degree of fineness of the wire itself, such as slits of different widths cut in polished iron rings, &c., which serve as gauges for this measurement.

The above means being provided, the wiredrawer's process commences with annealing the large wire received from the refiner, which is performed by placing it coiled upon lighted charcoal in a cylindrical cavity called the *pit* made for the purpose, and throwing more burning charcoal over it; the pit having no aperture at the bottom to admit air, the fire burns slowly, affording only sufficient heat to make the metal red hot without endangering its melting.

When it is cooled by being quenched in water, one end of it is passed through the first hole in the thick plate and fastened to an upright wooden cylinder six or eight inches in diameter, in the top of the cylinder are fixed two staples, and through these the long arm of the handle passes, by which the cylinder is turned on its axis by several men. In the continuation of this part of the process, the wire is frequently annealed and quenched, after passing through every hole or every other hole till it is brought to about the size of the small end of a tobacco pipe; and in this state it is cut into portions for the fine wiredrawers.

In this last part of the wiredrawing process it is not necessary to anneal, but it is still required to wax the wire at every hole; and as in this state much less force is required for drawing it through the plate, a different instrument is therefore used. A kind of wheel or circular piece of wood, much wider than the foregoing cylinder, is placed horizontally, having in its upper surface small holes at different distances from the axis, and into one or another of these, according to the force required, is occasionally inserted the point of an upright handle, whose upper end is received in a hole made in a cross bar above. From this the wire is wound off upon a smaller cylinder called a *rocket*, placed on the spindle of a spinning wheel; and this last cylinder being fixed on its axis behind the plate, the wire is again drawn

Mechanical
Processes.

Manufac-
tures.

through upon the first, and as it is now brought to the proper fineness, it is annealed to fit it for the flatting-mill. This annealing is performed in a manner rather different from the former, and with much less heat, for if the wire were now made red hot it would entirely lose its golden colour, and become black, bluish, or white, a fault frequently found in different parcels of gilt wire. It is now wound upon a large copper bobbin, which is set upright, some lighted charcoal or small coal placed round it and brought gradually nearer and nearer, and some small coals are put into the cavity of the bobbin; the wire must be carefully watched, and as soon as it appears of a proper colour it must be removed from the heat. This operation requires the greatest care, and is generally performed by the master: though the wire in a great measure retains the springiness which it had acquired in the drawing, yet it is not so soft as it might be made in a greater heat; it is nevertheless sufficiently so for yielding with ease to the flatting-mill.

The flat-
ting-mill.

(934.) The flatting-mill consists of two rollers, turned in a lathe to perfect roundness, exquisitely polished, placed with their axes parallel one over another, set by screws till their circumference comes almost in contact, and both are made to go round by one handle; the lowermost is about ten inches in diameter, the upper is commonly a little more than two, though some make it considerably larger, and indeed it would be more convenient if made as large, or nearly so, as the lower; their width and thickness are about an inch and a quarter. The wire unwinding from the bobbin, and passing first between the leaves of an old book pressed by a small weight which keeps it somewhat tight, and then through a narrow slit in an upright piece of wood called a catch, which gives notice of any knot or doubling, is directed, by means of a small conical hole in a piece of iron termed a guide, to any particular part of the width of the rolls, so that, should there be any imperfections or inequalities of the surface, the wire may be kept from those parts, and when one part is soiled by the passage of a length of wire, the wire may be shifted; till the whole width of the rolls being soiled, so as to require being cleaned and polished anew with the fine powder called putty, prepared by calcining a mixture of lead and tin: the workmen value the rolls from the number of places which the wire can thus be shifted to; good rolls will receive forty threads. The wire flattened between the rolls is wound again as it comes through on a bobbin, which is turned by a wheel fixed on the axis of one of the rolls, and so proportioned that the motion of the bobbin just keeps pace with that of the rolls.

Gilding.

Gilding of
the Ro-
mans.

(935.) The Art of gilding is intimately connected with that of gold beating, the latter indeed being useful only so far as it facilitates the former. A description of this process will therefore form a proper sequel to the preceding article. It has been said that, although the Ancients were not unacquainted with this Art, they possessed it in a very inferior degree compared with the Moderns, the leaves of gold they employed having been so thick that the process was very expensive and very rare; and, according to Pliny, the first gilding seen in Rome was subsequently to the destruction of Carthage, when the practice commenced of gilding the ceilings of temples and palaces, the Capitol being the first place on which this enrichment was bestowed.

VOL. VIII.

There are two sorts of gilding which differ essentially from each other, *i. e.* by metallic gold and by amalgam. The former is also divisible into two branches, according as it is effected by heat or applied cold.

Mechanical
Processes.

Gilding by amalgam.—This is practised only on metals, and is effected by heating pure quicksilver in a clean crucible, and when near boiling putting in about a sixth of its weight of fine gold in thin plates heated red hot, they are then stirred gently about till the gold is found melted and incorporated with the mercury. It is then allowed to cool, and put into a piece of soft leather, and by gradual pressure the fluid part of the amalgam, consisting almost entirely of mercury, may be forced through the pores of the leather, while the gold, combined with about twice its weight of mercury, remains behind, forming a yellowish silvery mass of about the consistence of soft butter, and with this the process (when the metal to be gilt is silver, copper, or alloys of copper with zinc) is, as nearly as the nature of the article will admit, conducted in a similar manner to that described for gilding buttons under the article *Button-making*. (685.)

Gilding by
amalgam.

Iron and steel also are sometimes gilded by amalgam, and sometimes by means of metallic gold, but in either way considerable difficulty is incurred. When the process is attempted with gold leaf, the difficulty consists in preventing oxidation during the heating of the iron; moreover, the temper of the metal, in such cases as sword-blades, daggers, &c., is liable to injury from the heat necessary to be employed, and this difficulty is by no means lessened by the use of amalgam. When the latter method is employed, a solution of mercury in nitrous acid, technically called quicksilver water, is applied to the parts intended to be gilded; then the acid, having an affinity for the iron, seizes a portion of it and deposits in its place a thin coating of mercury, which unites with the gold amalgam afterwards employed; but here the surface of the metal is injured, and the union of the mercury is very slight, so that a bright and durable gilding is not to be obtained.

Gilding
iron and
steel.

Another process, very little preferable to the former, is by means of sulphate of copper, a solution of which is applied with a camel-hair pencil to the parts intended to be gilt, when a chemical action similar to the former takes place and a coating of copper is precipitated, and, copper having an affinity for the mercury, a sort of union takes place between the steel and the gold; but whichever of these methods is adopted the surface is injured by the acid, and the temper by the heat which is necessary for driving off the mercury. Artists, therefore, generally, with all its disadvantages, prefer the process first mentioned, that is by heat and simply burning down the leaf.

Another
process.

Another process has been recommended which is supposed to be preferable to either before mentioned, for which we are indebted to an article in the *Phil. Mag.* vol. xi. Here the first part of the process consists in pouring over a solution of gold in nitro-muriatic acid and about twice as much ether, which must be done with caution and in a large vessel; the liquids must be shaken as soon as the mixture is at rest, and the ether will then separate itself from the nitro-muriatic acid and float on the surface. The nitro-muriatic acid becomes more transparent and the ether darker than they were before, the ether having taken the gold with the acid. The whole mixture is then poured into a glass funnel the lower aperture of which is small, but this aperture must not be opened

A third
process.

Manufac-
tures.

till the fluids have completely separated from each other. It is then to be opened, by which means the liquid which has taken the lowest place by its greater gravity, viz., the nitro-muriatic acid, will run off, after which the aperture is to be shut, and the funnel will then be found to contain nothing but ether mixed with the gold, which is to be put into well-closed bottles and preserved for use.

In order to gild iron or steel, the metal must first be polished with the finest emery, or rather with the finest *p* *crocus martis*, or *colcothar of vitriol*, and common brandy. The auriferous ether is then to be applied with a small brush, which soon evaporates, and the gold remains on the surface of the metal, which may then be put into the fire and afterwards polished. By means of this auriferous ether all kinds of figures may be delineated by employing a pen or fine brush, and it is in this manner, we believe, that the Sohlinger sabre blades are gilded.

Cold
gilding.

Cold gilding on silver.—This can be speedily done and with little trouble by dissolving gold in the nitro-muriatic acid, and dipping some linen rags into the solution; they are then to be burned, and the ashes, which will be very black and heavier than common, carefully preserved; they are then to be rubbed on the surface of the silver with the finger or a piece of leather or cork; by so doing the particles of gold they contain will be left on the surface of the metal. If the silver be then washed so as to remove the remaining part of the ashes, it will have scarcely any appearance of gilding, but on being burnished it will assume a beautiful gold colour: this method of gilding is very easy and requires very little gold.

Gilding of
brass.

Gilding of brass.—Five instruments of brass, in order that their surface may be kept longer clean, may be gilded in the following manner: saturated solution of gold is to be evaporated to the consistence of oil; it must be allowed to shoot into crystals which are to be dissolved in pure water, and the articles to be gilded being immersed in it, are then to be washed in pure water and afterwards burnished: this process may be repeated till the articles have been well gilt. A solution of gold crystals is preferred to a mere solution of gold, because in the latter there is always a portion of free acid which will not fail to exercise more or less action on the surface of the brass or copper and injure its surface.

Lackering
brass.

(936.) *Lackering of brass.*—The gilded appearance sometimes given to brass articles is produced by means of a solution of gum lac in spirits of wine, with which they are rubbed over; while the lac lasts they retain their splendour, but it will soon be destroyed if a strong brush or chalk are used in cleaning them. A varnish of this kind may be prepared in the following manner: two ounces of very pure and fine gum lac is to be dissolved in forty-eight ounces of alcohol, and the solution placed in a sand bath exposed to a moderate heat; to prevent the too abundant evaporation of the spirits of wine, as well as the bursting of the glass, a piece of bladder ought to be bound over the latter, and a few holes made in it with a needle; in another glass is to be dissolved, in the same quantity of spirits of wine, an ounce of dragon's blood in grains; now both the solutions being completed, they are to be mixed together, and three grains of yellow woad put to them, and to be allowed to remain twelve hours in a moderate heat, after which the liquor must be strained through a filtering paper and put into a glass bottle for use. To give this lac varnish a high colour, yellow woad is preferable to

every other substance, but if it is required to be pale and not to change the colour of the brass the yellow may be omitted, but if a stronger colour be required a half more of the yellow woad may be added.

Mechanical
Processes.

Gun-making.

(937.) The term gun-making is generally applied to the manufacturing of small arms only, such as muskets, fowling-pieces, pistols, &c. The making of the larger arms, as cannon, mortars, howitzers, and carronades, being commonly classed under the terms cannon-founding and boring. Gunpowder for the purpose of military attack and defence was first applied to the larger arms, the history of which has been traced under GUNPOWDER; and it appears that, very soon after this period, the smaller arm, or musket, was invented, but it still exceeded considerably in weight those found most effective in the present day, the bore having been much larger, and the weight so much greater that it was obliged to be supported on a fork when fired, which latter operation was effected by a match with priming powder; and under this form of match lock (although made much lighter) it remained in England till about the reign of Charles II., who, in 1638, granted a Charter to the Gunsmiths of London, by the name of Master, Warden, and Society of Gun-makers, and directed that, in future, the barrel should not be less than three feet in length, and the bore such as to carry a ball of which twelve should weigh a pound. The lock at this time was of the kind called the "wheel and snap lance." The invention of the flint and hammer lock succeeded this, but at what period it was introduced, or to whom we owe the invention, is not distinctly known. Beckmann, in his *History of Inventions*, says, "It is stated in the *History of the Brunswick Regiments*, that the soldiers of that Duchy first obtained, in 1687, flint locks instead of match locks;" but it is not said they were then first invented; indeed the immense variety of forms and gradations from one form to another is such as to make it extremely difficult to say when any particular form, or even a particular principle, was first employed. In the model room in the Repository at Woolwich is an extremely interesting collection of fire-arms and locks, from the first rude match lock to the present improved flint and percussion locks; but the different constructions are so blended that it is impossible to trace any very distinct step or improvement.

That the first means of discharge was with a match and priming powder is undoubted; and the next step seems to have been by attaching the match to a wheel, which might be turned round and the former thereby applied to the touchhole, so that a person might direct the gun and fire it at the same time. Next followed the wheel and fire-stone, the latter being screwed into the cock, and a steel plate or small wheel which could be cocked or wound up by a key. This fire-stone, however, was not at first of a vitreous nature or flint, like that at present used for striking fire, but a piece of compact pyrites; and as an instrument of such a kind was very liable to miss fire, a match was for a long time retained with the wheel, probably to the time of the invention of the flint lock.

Gun-making, in the larger manufactories, consists of several distinct operations, on each of which a different set of persons is employed, viz., the barrel-forging, borer and filer, lock-forging and filer, furniture-filer,

Gun-mak-
ing.
History of
the musket.

Practice of
gun-mak-
ing.

Manufactures.

ribber and breecher, rough stocker, screwer, polisher, and engraver, in all ten different parties, few of which can execute any branch of the Art except that in which they are engaged, at least they acquire, by this division of labour, a dexterity in one process which can scarcely be attained where a person is perpetually changing his occupation.

Forging the barrel.

(938.) *Barrel forging.*—In forming the common gun barrel the workman begins by heating and hammering out a bar of the best iron into the form of a flat ruler, thinner at the end intended for the muzzle, and thicker at that for the breech, the length, breadth, and thickness of the whole plate being regulated by the intended length, diameter, and weight of the barrel. This oblong plate is then, by repeated heating and hammering, turned round a cylindrical rod of steel or mandril, the diameter of which is considerably less than the intended bore of the barrel. The edges of the plate are made to overlap each other about half an inch, and are welded together by heating the tube in lengths of two or three inches at a time, and then hammering it with very brisk but moderate strokes upon an anvil which has a number of semicircular furrows in it adapted to barrels of different sizes.

The heat required for welding is the bright white heat which immediately precedes fusion, and at which the particles of the metal unite and blend so intimately with each other that, when properly managed, not a trace is left of their former separation. Every time the barrel is withdrawn from the forge, the workman strikes the end of it once or twice gently against the anvil in a horizontal direction; this operation, which is called jumping, serves to consolidate the particles of the metal more perfectly, as well as to disengage the scoria from the inside and outside of the tube and to obliterate any appearance of a seam. The mandril is then introduced into the bore or cavity, and the barrel being placed in one of the furrows or moulds of the anvil is hammered very briskly by two persons, the forger all the while turning it round in the mould, so that every part of the heated portion may come equally under the action of the hammer.

These heatings and hammerings are repeated until the whole of the barrel has undergone the same operation, and is rendered as perfectly continuous as if it had been bored out of a solid piece.

Pistol barrels.

Pistol barrels undergo the same process, except that those in particular which are to form pairs are forged in one piece, and are not cut asunder till after they have been bored, by which it is considered there is not only a saving of labour and material, but that greater accuracy is thus also obtained.

The barrel being completed to the extent above described is now to be finished by boring and filing or turning, as described below; but before explaining this process, it will be proper to speak of the twisted barrel, which is considered much superior to the common barrel, and is generally therefore preferred for fowling-pieces.

Twisted barrel.

(939.) The *twisted barrel* is forged in several pieces according to the following process, viz., four pieces of stub iron of two feet in length, half an inch in breadth, and two of the bars half an inch thick or more, according to the size of the barrel, are previously prepared, and an old gun barrel being welded to one of these to serve as a handle, it is heated and turned round like a cork-screw by means of the hammer and anvil, after which

the turns of the spiral are united by heating the tube a few inches at a time to a bright white heat, and by striking the end of it several times against the anvil in a horizontal direction with considerable force. This, as we have before said, is called jumping the barrel, and the heats given for that purpose are named jumping heats; a mandril is then introduced into the cavity, and a quick, light hammering is kept up on the welding part till the ridges raised at the seams by jumping are flattened and the piece appears sound; as soon as one bar is jumped and rounded in this manner, another is welded to it and treated in the same way till the four pieces are united and form one tube. The old barrel is then cut off as being no longer requisite, and the operation of heating and hammering is frequently repeated on its whole length, till its external figure is correctly acquired, and the metal has attained the desired closeness of texture and fibre.

Mechanical Processes.

Great care is necessary in this respect, in order to avoid the defects to which all gun barrels are liable; indeed, it is nearly impossible to say in any case that they have been avoided, and for this reason every barrel ought to be carefully proved before it is offered for sale.

The defects which barrels are subject to, the plain wrought ones in particular, are distinguished by the terms crack or *flaw*, and the *grey*; the former is a want of continuity on account of a defect of welding, which if detected in the proof* ought to lead to the condemnation of the barrel, although it is sometimes attempted to be mended. The latter is a small plate or scale which adheres to the barrel by a narrow neck, from which it spreads out as the head of a nail does from its shank, and when separated leaves a pit or hole in the metal; of these defects the grey is of the greatest consequence, and the most frequent, and is, when it occurs, a great disadvantage, by affording a lodgement for moisture and foulness which ultimately corrode the iron and

* The immense demand for muskets, and the consequent extent of the manufacture and receipt of them for the Government service, render it very essential that a well-regulated and careful mode of proof should be established. Accordingly, every musket received and passed at the Tower has undergone the following proof.

1. The barrel is charged with ten drachms of powder and a ball which fits the caliber, and two wads of brown paper; it is then laid on a bank and fired and left in that state for two days, to ascertain whether the damp of the powder has worked through any small crack. It is then washed and examined, and if found thus far good, it is marked with the King's proof mark.

2. Every piece is again examined after being sighted, and a single crown is then marked upon them.

3. They are again examined, when the break-offs are fitted before they are stocked.

4. The locks, bayonets, ramrods, brass-work, &c., are separately viewed.

5. The stocks are viewed when in a rough state, to see that the walnut is of good heart, and again when in a more forward state, and are then finally marked with the storekeeper's hammer, and entered on his books.

As there are thus several viewers, each has a particular mark, so that any defect passed by him may be traced to him in any subsequent stage.

The immense number of arms received and issued by the British Government may be estimated by the following authentic statement:

There were issued between the years 1803 and 1816	
Muskets	3,227,716
Carbines	118,103
Rifles	27,895
Pistols	203,266

In 1813, the allies of Great Britain were supplied with 500,000 muskets.

In 1815, there were at one time 1000 muskets per diem manufactured in Birmingham.

The number of muskets on store at the Tower is about 738,000.

Manufac-
tures.

enlarge the bore till the barrel bursts or becomes unsafe.

It is also a circumstance of considerable importance with respect to the excellence of a barrel, that it should be forged as nearly as possible to its weight when finished, so that very little may be taken away in the boring and filing, for as the outer surface, by having undergone the action of the hammer more immediately than any other part, is rendered more compact and dense, as little of it as possible should therefore be removed. Such is also the case, although in a less degree, with regard to that portion of the middle of the barrel which is to be cut out by the boring instrument.

Double bar-
rels.

Double barrels, or those intended for a double-barrelled piece, after having been dressed to their proper thickness, which is generally less than for single barrels, are filed flat on the sides that are to join each other, so that they may sit close together. Two corresponding notches are, then made at the muzzle and breech of each barrel, and into these are fitted two small pieces of iron to hold them more strongly together. The barrels being united by turning the parts which touch, the ribs are fitted in and made fast by the same means. These ribs are the triangular pieces of iron which are placed between the barrels, running on the upper and under sides their whole length, and serving to hold them more firmly together. The under rib is a recent improvement, serving more effectually than the single rib to prevent the barrels from warping.

(940.) *Indian gun barrels*.—The following description of the Indian method of working gun barrels in imitation of the Damascus steel, given by Captain Bagnold of Bombay, and presented by his brother Mr. J. M. Bagnold to the Society of Arts, will be interesting to the reader.

"The gun barrels made at Bombay in imitation of Damascus iron, so much valued by the Orientals for the beauty of their twist, are manufactured of iron hoops obtained from European casks, mostly British. The more these hoops are corroded with rust, the more are they acceptable to the workman; should there be any deficiency of this necessary oxidation, they are regularly exposed to moisture until they are sufficiently prepared for welding. Being cut into lengths of about twelve inches, they are formed into a pile an inch or an inch and a half high, laying the edges straight so as not to overlap each other; a longer piece is then so fitted as to return over each end and hold the whole together in the fire. This pile is then heated to a welding heat, and drawn out into a bar of about an inch wide and one-third of an inch thick; it is then doubled up in three or more lengths, and again welded and drawn out as before; and this operation is repeated generally to the third or fourth time, according to the degree of fineness of twist required. The bar is then to be heated about a third of its length at a time, and, being struck on the edge, is flattened the contrary way to that of the stratification. This part of the operation brings the wire or vein outwards upon the strap. The barrel is then forged in the usual way, but much more jumping is used than in the English method, in order to render the twist finer. The most careful workmen always make a practice of covering the part exposed to the fire with a lute composed of mud, clay, and the dung of cows or horses, in order to guard against any unnecessary oxidation of the metal. When the barrel is completed, the twist is raised by laying the barrel from one to five days either

in vinegar, or a solution of the sulphate of iron; this process is called the *wire twist*.

Mechanical
Processes.

"To produce the *curl*, the bars or straps are drawn into bars about three-quarters of an inch square, and twisted some to the right and others to the left hand; two of each sort are then welded together, doubled and drawn out as before described; and, according to the skill and experience of the workman, any intricacy of twist is produced by this drawing out, doubling, and twisting.

"Sometimes, to save trouble and economize the iron thus prepared, the artist will rough file an English barrel, weld a strap of Damascus iron spirally round it, or lay several straps longitudinally along it and weld it on. A native artist never works with pit coal under any consideration, charcoal from light wood forms his only fuel."

(941.) *Boring*.—The next operation is that of boring, in order to give to the barrel its proper caliber. The boring bit is a rod of iron somewhat longer than the barrel, one end being made to fit the socket of the crank, and the other being furnished with a cylindrical plug of tempered steel about an inch and a half in length, and having its surface cut in the manner of a perpetual screw, the threads being flat, about a quarter of an inch in breadth, and running with very little obliquity. This form gives the bit a very strong hold of the metal, and the threads being sharp at the edges, scoop out and remove every roughness and inequality from the inside of the barrel, and render the cavity smooth and equal throughout. A number of bits, each a little larger than the preceding one, are afterwards successively passed through the barrel in the same way, until it has acquired the intended caliber. The equality of the bore is of great moment, and it may be tried with tolerable accuracy, by means of a plug of lead cast on a rod of iron or wood, or even by a musket ball, filed so as to fit the bore exactly, and pushed through the barrel by the ramrod, care being taken not to use an iron ramrod or much force, lest the ball be flattened and an artificial difficulty created.

The gunsmiths afterwards polish the barrel; and it is then in a condition to receive its proper form and proportions externally by means of the file. To do this with accuracy, four flat sides or faces are first formed, then eight, then sixteen, and so on, until it is made quite round, except the reinforced part, which, in most of the modern work, is left with eight sides.

It is absolutely necessary to the soundness of a barrel that it should be of an equal thickness on every side, or, in the language of the workmen, a barrel ought to be perfectly upright. To accomplish this the gunsmiths sometimes employ an instrument which they call a "compass," consisting of an iron rod bent so as to form two parallel branches about an inch distant from each other. One of these branches is introduced into the barrel and kept closely applied to the side by means of one or more springs with which it is furnished; the other branch descends parallel to this on the outside, and has several screws passing through it with their points directed to the barrel. By screwing these until their points touch the surface of the barrel, and then turning the instrument round within the bore, it is seen where the metal is too thick, and how much it must be reduced in order to render every part of the barrel perfectly equal throughout its circumference.

A more perfect way of accomplishing this object, how-

Manufactures.

ever, is, after the barrels are bored true inside, to introduce two perfectly cylindrical mandrils, one at each end, to put them into a lathe, and to turn the outside to the proper dimensions.

Breeching.

(942.) *Breeching of guns.*—The barrels being thus far advanced, they have next to be breeched, which is done by screwing in a plug of iron at the end, in which is formed the chamber and vent. The screw is formed in the barrel first by means of a tool or conical tap of tempered steel, having upon its surface the proper threads; this being introduced into the barrel is turned from right to left and back again, till it has marked out three or four threads of the intended screw; another less conical tap is then introduced, and when this has carried on the impression of the screw so far as it is intended to go, a third tap is employed, which is nearly cylindrical, and scarcely differs from the plug of the breech, which is intended to fill the screw thus formed in the barrel. This screw is cut by a screw plate of tempered steel, or otherwise, according to the intended perfection of the piece when finished. Seven or eight threads are generally thought sufficient, and when cut neat and sharp it is case-hardened and introduced. In fig. 1, plate lxvii., is shown a section of the breech, patented by Mr. Nock, with the chamber *c*, ante-chamber *d*, and vent plug *f*. The particular form of breeching, however, differs considerably in different manufactories.

Pl. lxvii.
Fig. 1.

Colouring.

Colouring the barrel.—The next operation is that of giving to the outside of the barrel its proper colour, previously to which it is polished with fine emery and oil, until it presents to the eye through its whole length, and in whatever manner it is observed, a perfectly smooth and bright surface. In this state it may be given either the fine blue colour of tempered steel, or the bronze colour; the former by heating the barrel, but the latter, which is now generally preferred, as follows. In the bright state above described, the barrel is rubbed over with aqua fortis diluted with water, and in this way laid by till a complete coat of rust is formed upon its surface; a little oil is then applied, which being rubbed dry is polished by means of a hard brush and bee's-wax.

Rifle guns.

(943.) *Rifle guns.*—We have preferred to complete the account of the entire process of making gun barrels of the more usual kind before describing the rifle barrel, which is comparatively a modern improvement, generally attributed to the Germans, who are extremely fond of its use, as are also the Americans. The process of rifling is as follows. The barrel being forged and bored, as described in the preceding columns, is placed on the rifling machine, which is an instrument formed on a square plank of wood, seven feet long, to which is fitted a tube about one inch in diameter, with spiral grooves deeply cut internally through its whole length, and to which is attached a circular plate about five inches in diameter, accurately divided, in concentric circles, into from five to ten equal parts, and supported by two rings fixed to the plank on which it revolves: an arm connected with the driving plate, and pierced with holes through which a pin is passed, regulates the change of the tube in giving the required number of rifles to the barrel. An iron rod, with a movable handle at one end and a steel cutter in the other, passes through the rifling tube; this rod is covered with a core of lead one foot in length, and the barrel is firmly fixed by means of two rings on the plank, standing in a straight line to the tube; the rod is then repeatedly drawn through the whole length

of the barrel till the cutter has formed one groove to the proper depth; the pin being shifted to another hole in the dividing plate, the operation of grooving is continued till the whole number required is completed. The barrel is then taken out of the machine, and is finished by casting, on the end of a small iron rod, a core of lead, which, when coated with fine emery and oil, is drawn for a length of time by the workman from one end of the barrel to the other till the latter has acquired a high degree of smoothness and polish; it then passes into the hands of other workmen to be completed the same as other pieces.

Mechanical Processes.

(944.) *Theory of the rifle.*—Although the great advantage of rifling is universally admitted, considerable difference of opinion has existed as to the cause of this advantage, some attributing it to one principle and others to a different one. The first writer who undertook to examine the subject with proper attention was Mr. Robins, and he began by inquiring first into the cause of deflection in the common barrel. With this view he secured a musket barrel upon a block of wood, and firing with a ball at a board a foot square at 60 yards' distance, he found that it missed the board only once in sixteen successive discharges; yet when fired with a smaller charge at a distance of 760 yards, the ball was thrown sometimes 100 yards to the right or left of the line in which it was pointed. The direction upwards and downwards was also found equally uncertain, the ball in some discharges having struck the ground 200 yards nearer the piece than it did at others.

Robins's theory of the rifle.

It is not difficult to account for these irregularities; they doubtless proceed from the impossibility of fitting a ball so accurately to any plain barrel that it will not rub more against one side of the barrel than another in its passage through it. Whatever side, therefore, of the muzzle the ball is last in contact with on quitting the piece, it will acquire a whirling motion towards that side, and will be found to bend the line of its flight in the same direction, whether it be upwards or downwards, to the right or left, or obliquely, partaking in some degree of both; and after quitting the barrel, this deflection, which though in the first instance it is but trifling, is still further increased by the resistance of the air; this being greatest on that side where the whirling motion conspires with the progressive one, and least on that side where it is opposed to it. Thus if the ball in its passage out rubs against the left side of the barrel, it will whirl towards that side; and as the right side of the ball will, therefore, turn up against the air during its flight, the resistance of the air will become greater on the right side, and the ball be forced away to the left, which was the direction it whirled in. If the axis about which the rotary motion of the ball is made preserved its position during the whole of the flight, the deflection would be in the same direction from one end of the track to the other, though it is obvious that the quantity of this deflection would still not be proportional to the distance; for if all resistance of the ball were to cease at any part of its flight, still the ball would necessarily pursue the line in which it then moved, and the deflection be double at a double distance, treble at a treble distance, and so on. But as this resistance does not cease, but continues to act upon the ball throughout its whole flight, (though less in the latter part of it than at the commencement, in consequence of the decrease of velocity,) it is obvious that the deflection of the ball will be accelerated at every

Manufactures.

instant, and consequently increase in a greater proportion than the distance, as we have seen it has been found to do from the experiments above alluded to. It happens, however, from various accidental circumstances, that the axis of the ball's rotation frequently changes its position several times during the flight; so that the ball, instead of bending its course uniformly in the same direction, often describes a track variously contorted. So great, however, is the tendency of the ball to deflect itself against the side it rubs against, that it has been said, though we never saw the experiments authenticated, that a ball, when fired out of a barrel bent towards the left hand, and which will, therefore, be thrown from the piece in the direction of the bend, yet as the ball in this case will be forced to rub against the right side of the muzzle, and thus turn its left side up against the air, so it will be found to alter its course during the flight, and bend towards the right hand, so as to fall a considerable way to the right hand of the line in which the piece was pointed.

It will readily appear, therefore, from what has been stated, that these variations will be more frequent and considerable when the ball runs very loose in the piece, or when, from any roughness on its surface, or on the middle of the barrel, a considerable degree of friction takes place between them. With a view to prevent friction, it has been proposed to grease the ball; but this, we should imagine, would be of very little service. All that can be done in a plain barrel is to have the ball cast very solid and true, and afterwards milled, in the same manner as is now practised upon shot; the barrel also should be very smooth on the inside, and the ball fit in very accurately, so as to leave scarcely any windage; yet, with all these precautions, it is very difficult, we may say impossible, to prevent it entirely; for gravity will constantly act, and friction on the under side will naturally be occasioned by the weight of the ball. In fact, when we consider the causes of the aberration in the flight of balls, it will be pretty evident that the only means of correcting it is by preventing the ball from rubbing more against one side of the barrel than another in passing through it, and by giving to the bullet a motion which will counteract every accidental one, and preserve its direction by making the resistance of the air upon the fore part continue the same during its whole flight; that is, by giving it a rotary motion perpendicular to the line of direction.

Construction of gun locks.

(945.) *Gun lock.*—We have already, at the commencement of GUN, mentioned slightly the great variation which the form of the lock has undergone; to enter into a more particular description of the ancient contrivances of this kind would, it is conceived, but little interest the reader. We shall, therefore, simply refer to the common flint and steel lock and the percussion lock, the latter being comparatively a recent invention, although it has itself already undergone many changes. The common flint and steel lock is represented in fig. 2, 3, the former showing the works inside, and the latter the outside, the operation of which is too well known to require any particular description.

Pl. lxvii.
Fig. 2, 3.

Percussion lock by J. Manton.

Fig. 4, 5, 6.

The percussion lock was first invented by Rev. Mr. Forsyth, Minister of Belhelvie in Scotland; but the original form as given to it by the inventor is now wholly laid aside, as are several others which have succeeded it. One of the most recent, and which appears to possess many advantages, is a patent invention by Joseph Manton, the well-known gunsmith. This is represented in fig. 4, 5, 6,

&c., in which, instead of the usual percussion cap, a plug, shown in section in fig. 4, is employed; the centre part *a* being an iron pin, below which, in the small recess at *c*, the percussion composition is contained, slightly covered with a cement to preserve it in its place; *b b* is a plug of box wood, an elevation of the same is seen in fig. 5; fig. 6 shows the lock with a socket *s* attached, *h* being the hammer. The central hole in the socket is formed conical like the plug, and is precisely of the same size, with a form of a screw inside, so that by a slight pressure and turn of the hand, when the plug is introduced, it is safely retained in its place, and may remain there without any fear of displacement, or of injury from the weather. The gun is fired in the usual manner, when the force of the explosion splits the box plug, which falls out by a slight turn given to the musket; another plug may be then immediately introduced. At present, the percussion lock has not been introduced into the British army, but from experiments which have been made on this lock by authority of the Ordnance Board, at Woolwich, it is probable such may be soon the case. One objection to the introduction of the common cap was, that it was so small it could scarcely be felt when the hands were very cold and was likely to be dropped and lost; this objection is here avoided by the plug being of the full size shown in the figure; and from the results obtained in the experiments above alluded to its quickness of firing very far exceeds that of the common cap, in consequence of the explosion being placed so near the powder. We give the two following Tables from a report of Captain J. A. Chalmers of the Royal Artillery, which with other particulars he was authorized to furnish the patentee.

Mechanical Processes.

TABLE I.—Showing the comparative Failures in Forty Rounds of Ball Cartridges from each of six Muskets on Rivier's Percussion Cap, Manton's Percussion Plug, and Lovell's Flint and Steel Lock Principles, in heavy Rain. Comparative experiments on different locks.

	Rivier's Percussion Cap.	Joseph Manton and Son's Percussion Plugs.	Lovell's Flint and Steel Locks.
	Failures.	Failures.	Failures.
From 1st to 10th round	7	2	38 and 4 hang fires.
From 11th to 20th do.	1	None	11 and 2 ditto
From 21st to 30th do.	2	None	9 and 2 ditto
From 31st to 40th do.	5	None	12 and 3 ditto
Total failures.....	15	2	70
In 240 rounds the proportions of failures . }	1 in 16	1 in 120	1 in 3½ nearly

N. B. All the flints in Lovell's muskets were exchanged after the twentieth round, and two extra to replace broken ones; thermometer 47°, barometer 28° 8'; wind strong gale from South South-West. Heavy rain during the whole practice, but at the worst during the first ten rounds, and the greater number of failures at the beginning is to be accounted for from the heavy rain in marching from the barracks to the ground for practice twenty-five minutes; the muskets were therefore very wet before they were loaded.

Manufactures.

TABLE II.—Showing the comparative Failures in One Hundred Rounds of Ball Cartridges fired from each of six Muskets on the Percussion Cap, Percussion Plug, and Lovell's Flint and Steel Lock Principles in fine Weather.

	Rivier's Percussion Cap.	Joseph Manton and Son's Percussion Plugs.	Lovell's Flint and Steel Locks.
	Failures.	Failures.	Failures.
From 1st to 10th round.	None	None	2
From 11th to 20th do.	1	None	1
From 21st to 30th do.	None	None	None
From 31st to 40th do.	2	None	4
From 41st to 50th do.	None	None	5
From 51st to 60th do.	3	None	8
From 61st to 70th do.	1	None	8
From 71st to 80th do.	4	None	10
From 81st to 90th do.	2	1	6
From 91st to 100th do.	1	1	2
Total failures	14	2	46
In 66 rounds the proportions of failures were }	1 in 43	1 in 300	1 in 13

N. B. After the sixty-ninth round the muskets were loaded and piled in the open air, they remained so three hours, when the practice was resumed without cleaning the muskets. The flints in Lovell's muskets were changed after every twenty rounds, and in addition to replace broken ones.

In Rivier's four primes were dropped; in Manton's two during the practice.

Locks for ships' guns.

(946.) *Locks for ship ordnance.*—Till of late years ships' guns were fired by slow match and priming powder, but subsequently steel and flint locks have been employed, which resemble in a great measure, except in size, the common musket lock, and still more recently attempts have been made to introduce the percussion principle. As first tried by the late Sir William Congreve, the hammer was simply attached to the breech of the gun, forming a kind of bent lever turning on a joint at the angle; to the shorter arm a string was attached, by a smart pull at which the hammer turned on its joint and struck the percussion cap over the vent and thus fired the gun; but it was found that the sudden return of the hammer from the explosive force of the powder was such as generally to destroy it in a very short time. To remedy this defect, Mr. James Marsh, an ingenious artisan in the Royal Arsenal, has invented a different tube, viz., one which is bent at right angles, whereby the percussion powder is not placed over the vent but on the vent field, whereby the former evil is avoided, and, as far as the experiment goes, they promise to be completely successful.

Gun-flints.

(947.) *Gun-flints.*—The art of forming gun-flints, as appears by the account given by Beckmann, was kept as a great secret in France and Germany, although we see it frequently publicly exhibited in different parts of England. The masses of flint which are best fitted for this purpose are of a convex surface approaching to globular. The knobbed and branched flints are commonly full of imperfections. The best flint nodules are generally between two and twenty pounds in weight. They

should be unctuous or rather shining internally, with a grain so fine as to be imperceptible to the eye, the colour should be uniform in the same nodule, and may vary from honey-yellow to a blackish-brown; it is likewise necessary that the fracture should be smooth and equal, the fragments slightly conchoidal, and the transparency should be such as to allow letters to be distinguished through a thickness of one-fourth of a line when laid close to the paper. Flints which do not possess these properties, either naturally or after a long exposure to the air, are rejected by the workmen.

Mechanical Processes.

Four tools are necessary in the manufacture of gun-flints; first, an iron hammer with a square head, a handle seven or eight inches long, and not exceeding two pounds in weight. This instrument is shown in fig. 7, plate lxvii. Secondly, a hammer of well-hardened steel with two points, a handle seven inches long, and from ten to sixteen ounces in weight. The handle must pass through in the same manner that the two points may be nearer the hand of the workman than the centre of gravity of the mass. This hammer is represented in fig. 8. Thirdly, a disk hammer or roller, like a solid wheel or the section of a cylinder, two inches and four lines in diameter, and not exceeding twelve ounces in weight. It is made of steel not hardened, and has a handle six inches long, which passes through a square hole in the centre. It is shown in fig. 9. Fourthly, a chisel tapering and bevelled at both ends, which should be made of steel not hardened, and six, seven, or eight inches long, and two inches wide. This chisel is represented in fig. 10; it is set upon a wooden block which is also used as a bench for the workmen; a file is necessary for restoring the edge of the chisel. With these tools the flints are formed in the following manner, which we have abridged from Dolomieu's Memoir.

Description of tools.

Pl. lxvii. Fig. 7, 8, 9, 10.

1. *To break the block.*—The workman seated on the ground places the nodule of flint on his left thigh, and applies slight strokes with the square hammer to divide it into smaller pieces of about a pound and a half each with broad surfaces and almost even fracture.

Processes described.

2. *To cleave or chip the flint.*—The workman holds the piece of flint in his left hand, not supported, and strikes with the pointed hammer, fig. 8, on the edges of the great planes produced by the first breaking, by which means the white coating of the flint is removed in the form of small scales, and the mass of flint itself laid bare in the manner represented, (fig. 11,) after which he continues to chip off similar scaly portions from the pure mass of the flint; these scaly portions are nearly one inch and a half wide, two inches and a half long, and their thickness in the middle is of about two lines. They are slightly convex below, and consequently leave in the part of the flint from which they are separated a space slightly concave, longitudinally bordered by two rather projecting straight lines or ridges, fig. 12. These ridges, produced by the separation of the two scales, must naturally constitute nearly the middle of the subsequent piece, and such scales alone as have their ridges thus placed in the middle are fit to be made into gun-flints. In this manner the workmen continue to split or chip the mass of flint in various directions, until the defects usually found in the interior render it impossible to make the fracture required, or until the piece is reduced too much to receive the small blows by which the flint is divided.

Fig. 11, 12.

3. *To shape the gun-flint.*—Five different parts may

Manufac-
tures.

be distinguished in a gun-flint. First, the sloping face or bevel part which is impelled against the hammer of the lock of the gun. Its width should be about three-twelfths of an inch, if it were broader it would be too liable to break, and if more obtuse, the scintillation would be less brisk. Secondly, the sides are lateral ridges, which are always rather irregular. Thirdly, the back or the part opposite the tapering edge; this is the thickest part of the flint. Fourthly, the under surface, which is uninterrupted and rather convex; and fifthly, the upper face or small square facet between the tapering edge and the back which receives the upper claw of the cock; it is slightly concave. In order to fashion the flint, those scales are selected that have at least one of the above-mentioned longitudinal ridges. The workman fixes on one of the tapering borders to form the striking edge, after which the two sides of the stone that are to form the lateral edges, as well as the part which is to form the back, are successively placed on the edge of the chisel in such a manner that the convex surface of the flint, which rests on the forefinger of his left hand, is turned towards that tool; he then with the tool, fig. 10, applies some slight strokes to the flint just opposite the edge of the chisel underneath, by which means the flint breaks exactly along the edge of the chisel.

4. *To trim the flint.*—The last operation is to trim or give the flint a smooth and equal edge; this is done by turning the stone, and placing the edge of its tapering end on the chisel, in which situation it is completed by five or six slight strokes with the round hammer. See fig. 13.

The whole operation of making a gun-flint is performed in less than one minute. A good workman is able to manufacture a thousand good chips or scales per day, (if the flint nodules be of a good quality,) and in the same manner he can fashion five hundred gun-flints in the same time, so that, in the space of three days, he is able to cleave and finish a thousand gun-flints without further assistance.

In this manner five or six blows with the hammer are sufficient to produce a perfection of figure which would require more than an hour's labour if the faces were formed by grinding them against harder substances; and less than a farthing will pay for a flint from the hand of the workman, though fifty times that sum would be insufficient to purchase it if it were formed in any other way.

When the gun-flints are completed, they are sorted into two classes, fine and common flints, and according to their application into flints for pistols, fowling-pieces, and muskets. A good gun-flint will give fifty strokes without being unfit for service. They are sold in France at from four-pence halfpenny to seven-pence per hundred; their cost is twice that in Italy; and in 1745, when they were exported from the Department of the Loire and Cher to Lyons, Strasburg, and St. Quintin, they cost twelve francs per thousand, or one shilling per hundred.

The manufacture of gun-flints in France employed above 800 of the inhabitants in the Communes of Noyers, Couffy, and Meunes, in the Department of the Loire and Cher. The mine, which is four leagues square, is thirty or forty feet deep, and 30,000,000 of flints manufactured here were stored up in 1794. They are also made in the Communes of Lye, in the Department of the Indre, of Maysse and St. Vincent, in the

Department of Ardeche, and at Cerilly, in the Department of the Yonne. Dolomieu received the information contained above from Stephen Buffet, who emigrated from the Commune of Meunes to the banks of the Seine, where he carried on his profession for above thirty years.

Gun-flints are made also in the territory of Vicenza and in one of the Cantons of Sicily. They were manufactured in great quantities at Stevensklint in Zeeland. There is a manufactory of flints at Purfleet in Kent, and they are likewise made in various other parts of England in very superior style.

See Dolomieu's Memoir in the *Mémoires de l'Institut*, vol. iii. p. 148; in the *Journal des Mines*, No. 33, p. 693; and in Nicholson's *Journal*, vol. i. Svo. p. 88; in the *Journal des Mines*, No. 33, p. 713, 719, will also be found a Memoir by M. Solivet, and observations by M. Tonellier on the manufacture of gun-flints in the Commune of Cerilly. See also the *Hanoverian Magazine* for 1772; and Beckmann, *History of Inventions*, vol. iv. p. 609, &c.

Nail-making.

(948.) As we intend only to describe in this section such mechanical processes as are effected by machinery, we might pass over unnoticed the old method of forging nails, but the article would, perhaps, in that case be thought somewhat incomplete; we therefore propose to describe the method of forging nails, but as concisely as possible. The iron used for these kinds of articles is not of the best quality; it is rolled first into thin bars, and then slit down into rods of proper size for different kinds of nails; a small forge and small pair of bellows only are required, and the work was therefore formerly, and is at present, where it is continued, carried on by nailers at their own cottages. The rods being very thin, three or more may be heated at a time; one of them having a good red heat is then taken out of the fire, and worked on an anvil to a square sharp point by a very few blows; the nailer now applies it over the edge of a fixed chisel, at a certain distance from which is a bar, so that by pushing the point against the bar and striking a single blow over the chisel the nail falls off into a tin pan; the lengths being thus all alike, the iron is still sufficiently hot to form another such piece, but the rod is then returned to the fire. The workman next with a pair of tongs takes up the nail and introduces its point into a square tapering hole made across through the end of an iron tool or mould, and by striking a blow or two on the end of the iron he flattens it down and forms the head, the intended figure of which is acquired by a few blows dexterously applied. This process is indeed conducted with surprising rapidity, the nailers by long practice having acquired a mechanical habit of forming an entire nail by a certain number of blows, and it is very rarely an unnecessary blow is given.

In the larger nails only one can be made and cut off at each time the iron is taken from the fire, because the workman would be unable to get the heading finished whilst the iron was sufficiently hot. The length of the nail, of whatever size, is regulated by a stop fixed at a certain distance from the edge of the chisel as above described, so that the point of the nail being applied to this determines the proper place for the edge of the chisel. The size of the mould withinside, and the dimensions to which the point of the nail is reduced by

Mechanical
Processes.

Nail-
making.

Old method
of forging.

Manufactures.

hammering, causes the cut end to project above the surface of the mould more or less; so that the head will be thicker or thinner, and have its quantity of metal regulated, by the degree of taper given to the point; therefore the art of the workman is displayed in striking with a due force, so that every nail shall be made of the same size by a certain number of blows. In this manner the greatest number of all nails were formerly made; but the great expense of labour has induced many manufacturers to turn their attention to inventions which would diminish the labour, whereby to enable them to bring their nails to the market at reduced prices, or of a better quality.

Nail-making by machinery.

(949.) These considerations have given rise to various patented inventions for nail-making machinery. The first was that of Mr. French, of Wimbourne in Stafford, in 1790; but it consisted of little more than working the hammer by water power, which enabled children to become nailers, as they had only to place the rods beneath the hammers; that is, one person brought the rod from the fire to another stationed before the hammer, who turned it about, formed the nail, and cut it off; it was then taken to the header, the operation being however still nearly as above described, except that the hammer in this case also was worked by the machinery.

About the same time, Mr. Clifford of Bristol took out a Patent with a like object, and, subsequently, another on a different principle.

Clifford's first Patent.

(950.) The first of these inventions consisted of making the nail in a die, that is, by having a die, or the impression of the nail to be cut, formed in one or more pieces of steel, and the iron of which the nails are to be formed drawn or rolled into the proper form and thickness, and by a force adapted to the purpose pressed into the cavity of the die, so as to form the nails either complete, or so nearly complete that they could be finished with very little labour.

The rollers are described as being made of iron cased with steel, each of the same diameter, which is proportioned to the length and size of the nail intended to be made. Each roller should have a cog wheel on it, the cogs of one roller working into those of the other, so that both the rollers may perform the same exact revolution. One half the impress of the nail is to be cut in the surface of one roller, the other half in the other, whereby the two impressions form a cavity or die of the exact form of a nail, extending lengthways of the nail on the circumference of the rollers; and as many impressions of the same kind may be cut in the rollers, one at the end of the other, as will complete their circumference and continue the cavity all round the rollers, the point of one nail joining the head of the next, or the two points and two heads joining each other. The rollers must, in this as in other cases, be made to work very truly and closely to each other.

The mode of operation is this: a rod of iron, previously rolled or drawn to a convenient size, is to be heated, and, while hot, the end of it is put between the rollers into the cavity or die which forms the impression of the nail; the roller being now put in motion, will draw the iron through, and the pressing it into the cavities or dies forms the iron into nails, one joined to the other, which must afterwards be separated by means of instruments acting as nippers, shears, chisels, &c. The rollers, being made to work very closely to each other where the edge of the nail is formed, will prevent much of the metal from being pressed out on each side of the

nail, and what is pressed out may be cut off by instruments adapted to the purpose. Several pairs of rollers may be made to work together, and each pair may have several rows or dies cut on them, so as to form the impression for several strings of nails; and a rod of iron being put into each of them will roll out as many strings of nails with one revolution of rollers. A pair of rollers may also have the greater part of their surface cut with dies, and a flat bar made to pass between the rollers so as to form sheet nails, all of them connected to one another by thin plates of the iron of which they are composed; this also would require each nail to be cut out or separated from the sheet by proper instruments.

Mechanical Processes.

(951.) Mr. Clifford's second invention consists, first, in drawing the iron or other metal into a tapering or wedge-like form, according to the length and thickness of the different sizes of nails to be made. Secondly, the nails are to be cut out of those wedge-like or tapering plates by means of a punch, the face of which is made according to the size, taper, and form of the nail to be cut out; as also having a hollow bolster, the hollow or aperture of which must also be made of the size and form of a nail, and consequently to fit and receive the punch above mentioned. The punch thus fitted to the bed, and sliding in a proper frame to keep it steady, will, by a blow or by pressure, cut or force part of the taper plate into and through the aperture of the bed fitting to it, and thereby form the nail. This operation is by the manufacturers of buckles, buttons, &c. called cutting out. Thirdly, to form the heads of horse nails, called rose heads, and others of nearly a similar kind: after the operations of drawing and cutting out, the nail is to be put into a heading tool, also called a bed, which bed receives the nails, excepting a small portion at the thick end, out of which the head is formed by a punch or die. This die, by blow or pressure, forms the head as required, and when the nails are made of hard iron, after they are cut in the way described, the thick end is made hot before they are put into the bed or heading tool. Fourthly, another method adopted in the manufacture of nails is by cutting them out of or from plates of equal thickness, and afterwards to point them either by hammer or other pressure. Fifthly, in making nails that are of a triangular form, the plate or strip of iron is pressed or stamped into a die having impressions cut to the form of such nails, after which they are cut out by a punch.

Clifford's second Patent.

Another Patent for forming nails was taken out by Willmore & Messrs. Willmore and Tonk, which is described as follows by the patentees.

"We take a nail rod suitable to the size of the intended nail, and, applying it to a common screw press mounted with proper cutters, cut off from the end of the rod two pieces at once, obliquely across the rod in one place, and directly across it in another, as is shown in fig. 1, plate lxviii. at *a e* and *b*. Two studs or stops are set up, one at *c* and the other at *d*, which are attached to the press, and are adjustable by screws or other means, the stud *c* being adjustable or movable in the direction of the rod for the purpose of ascertaining the length of the nail, both *c* and *d* being adjustable in the cross direction of the rod, so that the latter being pressed gently always against *c*, and sideways against *c* and *d*, the obliquity of the cut, according to the kind of nail to be made, is thereby determined, as well as the length of the nail; the length of the two pieces may either be

Pl. lxviii. Fig. 1, 2.

Manufac-
tures.

nearly equal or unequal, by means of the said adjustments, as will be evident on due consideration. This may be called the first operation. The next is to anneal the pieces so cut off, if the iron should not be sufficiently malleable, which is done in the usual and well-known manner. The third operation is that of heading, which for clasp-headed nails consists of two parts, one for gathering and the other for forming the head of the nail. The first part of this operation is performed by putting a piece cut off the rod of iron, as before described, into a pair of clams, leaving as much of the thick end projecting above the clams as is sufficient to form the head. These clams, have steel bits let into them with sharp edges, which press only against the two opposite sides of the piece, and which have the effect of two chisels when the punch of the press is brought down upon the piece with considerable force, and raise or gather up iron on each side towards forming the head. The second part of this operation is to put the piece thus prepared into another pair of clams, having bits formed to correspond to the under side of the head; and the punch, having the impression of the upper side of the head engraved or sunk into it, is brought to press strongly upon the head in the clams, and thereby the clasp head is properly formed. For nails intended to have rose heads, or any other kind except clasp heads, the first part of the operation is not absolutely necessary, though we think it advisable to be done, but the bits, which for clasp nails must have sharp edges, must for other kind of nails have blunt edges, to prevent the under cutting. For the second part of this operation the piece is put either into a pair of clams or into the tool commonly called a bore, and then pressed with punches, properly engraved or sunk, according to the kind of head wanted. By the third operation the piece cut off the rod is formed something like a mortise chisel, and the next or fourth operation is to point it, which is done by putting the piece into a bed of steel, in which is cut a nick or groove *d*, having parallel sides, as in the plan C, fig. 2, but the bottom rising towards the end where the point of the nail is to be formed, as seen in the section B of the bed. The punch is shown at A, and the end which presses upon the point of the nail is made to project further than the other part, so as to meet the corresponding part of the bed when the punch is brought upon the nail. The groove or nick in the bed should be just wide enough to receive the piece easily, but it must prevent it from twisting when the impression is made. The piece is put twice into the nick, once with the chisel end lying horizontal, and next turned a quarter to press the chisel edge into a pointed form. If the nails, by the strong pressure which is necessary in this operation, should become too hard to clinch, we in such case anneal them in the ordinary way, which may be called the fifth operation.

"The third, fourth, and fifth operations above described are applied to nails or pieces cut off from the sheet or rolled iron in the ordinary way; but as they, in consequence of the fifth operation, which is necessary to give them the quality of clinching, are apt to be too soft to drive well, we apply a sixth operation, *viz.*, quenching them when red hot in water, or other proper fluid, which gives them stiffness enough to drive without destroying the quality of clinching.

"Fig. 3 shows a pair of clams with bits or dies let into them, which can be renewed from time to time with more ease and at less expense than by the usual method.

These bits are proper for the first part of the third operation. Mechanical Processes.

"Fig. 4 a pair of bits or dies proper for making either rose heads or flat heads.

"Fig. 5 a pair of bits or dies proper for the second part of the third operation for clasp-head nails: the dotted line shows the head of the nail."

(952.) Another Patent, taken out by Mr. Daniel Ledsam and W. Jones of Birmingham in 1827, is thus described in vol. xlv. of the *Repertory of Arts*. Ledsam's Patent.

The first part of the machinery consists of a frame, supported on two horizontal pivots, which carries two movable and two fixed cutters, (the edges of which come in contact so as to cut like the blades of scissors,) and is so placed beneath vertical rods of metal that are made to descend between the cutters as to nip off from them small portions of the metal in the shape of the brads or nails required.

The use of the cutter frame being suspended on pivots is to allow the edges of the cutter to be inclined a small degree to the rods, in order that the pieces nipped off from their extremities may be pointed, and, as the inclination of the frame is shifted alternately to opposite directions, the side of the rod, from which the point of the last brad was cut, becomes that from which the head of the next brad is divided, and so on in a regular order reversed at each vibration of the frame. To give this movement to the frame, a horizontal axle is made to revolve beneath it by mill-work, on which an eccentric wheel is fixed vertically, which acts between parallel arms, descending perpendicularly from one end of the cutter frame, and, in turning, forces them a certain distance from the axle, first to one side and then to the other; this movement causes the frame to make a similar change of position with regard to the horizontal line between its pivots. There is also a crank on the same axle which moves the acting cutters forwards and backwards by a short connecting rod, in the following manner. Each of these two cutters is fastened to a flat rectangular plate, the ends of which slide in grooves prepared for them in the inner sides of the vibrating frame; and in the middle between these plates a flat hinge (like a common door hinge) is placed with its sides jointed to the opposite plates, while its own "knuckle," or joint, is connected by its pivot with the connecting rod of the crank; by these means, when the crank ascends, the knuckle of the hinge is raised, and the two cutters and sliding plates are thereby made to approach the centre of the frame; and when again the crank descends in revolving, the knuckle of the hinge is drawn down to a level with the sliding plates, and they and the acting cutters, by the expansion of the sides of the hinge, are forced outward from the centre, over the edges of the fixed cutters, so as to nip off the portions of the metallic rods that constitute the brads or nails.

A variation of this latter part of the contrivance is described in the specification, in which the plates that hold the acting cutters, instead of sliding in grooves, are supported by vertical pieces that are joined to them at their upper ends, and at their lower ends to additional horizontal bars attached to the vibrating frame underneath; this appears to us a better method of effecting the intended movement than the first.

The eccentric wheel on the axle, by which the vibrating frame receives the movement from which it is denominated, is made to alter its degree of eccentricity by having a rectangular cavity cut through its middle, in

Manufactures.

which a piece of the same shape that surrounds the main axle is drawn further from the centre or pressed nearer to it, as required by a screw, whose extreme end is connected to it by a pin which passes across the side of a groove turned in it for that purpose, and has its stem inserted in a hole drilled for it through the thickness of the eccentric wheel in the direction of its diameter.

The metallic rods from which the nails or brads are cut, and which may be of iron, copper, brass, or other fit metals, are brought down between the acting and fixed cutters by weights of a due size, which slide down strong wires that are stretched from a rafter (apparently, from the drawing, placed across the upper part of the room in which the machine is fixed) to a frame; but the method in which they are fastened to this latter, and some other particulars of their arrangement, are not explained with any degree of accuracy in the specification. A considerable number of these wires and rods with their weights, shaped something like pistols, are represented in the drawing, while parallel to each other, to be acted on by one pair of cutters, which also seem to be an arrangement that is faulty either as to contrivance or with regard to its insertion in the specification.

The machine is made, when required to form the kind of brads called sparrow-bills, (which have a small projection from one side of their heads,) by a piece of metal in the nature of an inclined plane that rises from the fixed frame; and which, as this latter is moved up and down, comes in contact with the bars to which the lower ends of the wires that sustain the rod weights are fastened, and thereby presses them a very small distance to one side, which is necessary to preserve the portion of the rod intended for the projection of the sparrow-bill from the action of the cutters.

Weight of nails exported.

(953.) The great extent of the nail manufacture in this Country may be seen by the following Returns of iron exported in this form, besides the immense amount necessarily employed for home consumption. The export of nails from 1820 to 1831 was as below.

Years.	Tons of Nails exported.	Years.	Tons of Nails exported.
1820	2847	1826	3538
1821	3288	1827	3957
1822	3353	1828	4596
1823	3785	1829	4528
1824	3980	1830	4818
1825	3555	1831	4361

Needle-making.

Needle-making, old process.

(954.) In the manufacture of needles there is but little machinery employed, and there was formerly much less; for the wire having been first reduced to the proper dimensions by drawing was then cut to the proper lengths; these were flattened at one end to form the place for the eye; they were then softened in a fire, and the eye punched out by hand with a small punch and hammer; the heads were then trimmed off with a file, and the cavity on each side also filed out. But the modern process is as follows.

Modern process.

The wire when drawn to a proper size, which is ascertained by gauges, is made up into coils for package; these coils of wire are heated to a dull red heat in a furnace, and suffered to cool gradually, to soften and

Mechanical Processes.

anneal it, with a view of facilitating the working of the steel; this commences by cutting the wire into lengths, which is done by a pair of shears. The workman being seated before a bench takes, perhaps, a hundred pieces of wire for fine needles, and introduces their ends between the blades, which he opens with his right hand, and presses the ends of the wire against the gauge, which renders them all one length; he cuts them off, and they drop down into a tin pan placed on a small shelf in front of the bench; the ends of the wire are now pressed against the gauge and cut off again. In this way the wires are cut into lengths of the required needles. The second operation is flattening the end for the eye of the needle, which is done by a workman taking three or four pieces of the wire between his finger and thumb, placing them on a small anvil, and striking one blow upon each expands the end sufficiently to receive the point of the punch which pierces the eye. This the same person does before he lays them down with a small instrument fixed on the same block as that to which the anvil is fixed. The end of the needle is placed in a small notch in the bed of the instrument and is put exactly beneath the punch, a slight stroke of the hammer punches the eye, and at the same time forms the semicircular groove near the eye of the needle to bury the thread. The notch which receives the needle is made in a piece of steel which fits into a dove-tail notch in the bed of the instrument, so that it can be changed for a larger or smaller, correspondent to the size of the needles to be pierced. The workman holds the needles in the same manner as he did for flattening, and, placing them one by one successively in the notch in the bed-piece, pierces them by striking a single blow of his hammer on the end of a slider; the slider is immediately returned by a spring. He now places the next needle under the punch, and when they are all pierced in this manner he rolls them over by moving his thumb so as to turn them all half round and bring them upwards, the opposite to that side which was pierced; this being done, he repeats the punching on the other side, with a view to finish and clear the eye and to form the groove which there is in all needles. They are now rounded at the eye end to take off the roughness, which is done in an instant by applying them to a grindstone.

The next process is hardening and tempering. The first is done by placing a great number together upon a piece of iron, bent up at the ends and sides that they may not roll off, and introducing them into a small furnace; when they become of a red heat, they are taken out and suddenly plunged into a vessel of cold water; this renders them very hard. Some manufacturers make use of oil, or tallow, and other ingredients instead of water, which substances are supposed to improve the process. The needles thus hardened are returned to the furnace with the oil upon them, and remain there till the oil inflames, when they are withdrawn and again cooled with cold water. This second process tempers them; at first they were quite hard, and so brittle as to break with the slightest touch; the tempering takes off the brittleness, but leaves them hard enough to take a good point. When they are hardened in water according to the old method, the heat for tempering them can only be guessed at or estimated by experience; but the flaming of the oil is a much more certain method. The needles are now examined, and many of them will be found crooked by hardening,

Manufac-
tures.

which are discovered by rolling them over as they lay in rows on a board, and such are selected and made straight by a blow in the notch in the anvil. Being thus straightened they require to be pointed, which is done by a large grindstone turned by a mill either of water or steam. In this operation the workman, sitting astride before the stone on a block shaped like a saddle, takes up twenty or thirty needles, laid side by side across a small wooden ruler covered with soft leather, another similar ruler being laid over the needles to confine them; he then holds the rulers in his hands, and thus presenting the ends of the needles to the grindstone points them with great dexterity. This operation has been found extremely injurious to the individuals employed, and a method for correcting or alleviating this evil is described at the end of this section. After pointing, they are polished by rolling them in emery powder and olive oil. The points are next finished and rendered perfectly sharp by grinding them upon a wooden wheel covered with emery, being held in the same manner as for the first grinding. They are then cleaned and packed up in certain numbers according to their sizes, and a great number of small packets are made into large parcels, wrapped in several thicknesses of paper, and coverings of bladder and packing-cloth, in which state they are sent to market.

Surgeons'
needles.

(955.) Surgeons' needles are generally made crooked and their points triangular; however, they are of different forms and sizes, and bear different names, according to the purposes they are used for. The largest are needles for amputation; the next kind for wounds; the finest needles are for sutures. They have others very short and flat for tendons; others still shorter, and the eye placed in the middle, for the tying together of vessels, &c. Needles for couching cataracts are of various kinds, all of which have a small, broad, and sharp point or tongue, and some with a sulcus at the point. Surgeons have sometimes used two needles in this operation; one with a sharp point for perforating the coat of the eye, and another with a more obtuse point for depressing or couching the opaque crystalline lens; but care should be taken in the use of any of these that they be first well polished with cloth or leather before they are applied.

(956.) We shall close this short notice with an account of a patent invention for the manufacture of needles of all sorts by Mr. William Bell of Walsall, which we shall give in his own words.

Bell's
Patent.

"The method by which I make needles, bodkins, fish-hooks, knitting-pins, netting-needles, and sail-needles, is by casting them with steel or common fusible iron, called pig or cast iron, into moulds or flasks made with fine sand; or, otherwise, I make the stock or moulds of iron or steel, or any other composition capable of being made into moulds, on which stocks or moulds I sink, engrave, or stamp impressions of the said articles. Into these I pour my melted iron or steel, (I prefer for my purpose sand casting,) and prepare my iron or steel as follows: I melt it in a pot or crucible, in small quantities about the weight of twelve pounds, (and upwards, to twenty pounds,) the more conveniently to divest it of its heterogeneous particles, and to purify it from its earthy or sulphureous qualities. When the iron has attained a proper heat, I take charcoal dust mixed with lime or common salt, which I throw into the pot of melted iron; and by frequently stirring it with an iron rod I bring to the surface of the iron a scoria, which I

frequently skim off, and thus bring my iron into a refined state; I then pour it into the mould before described. The articles being thus formed are capable of being softened, hardened, or tempered in the usual way, by which needles and sail-needles have heretofore been manufactured; therefore the principal merit of my invention is in casting them, instead of making them in the usual way."

(957.) *Needle and other dry grinding.*—In the preceding part of this section we have alluded to the injurious effect of needle grinding upon the health of the individuals, very few of whom are said to reach more than the age of forty, from constantly inhaling the dust thrown off from the needle points and from the grindstone. This evil attracted the attention of the managers of the Society of Arts, who in consequence offered a premium to any person who should propose some remedy for this evil, and accordingly several propositions were made and rewarded; but the most approved was one by Mr. J. H. Abraham of Sheffield, which is as follows: fig. 6, 7, 8, Pl. lxviii. are a section and a back elevation of a needle grinder's wheel, in which *a* is the wheel, *b b* the trams on which it is mounted, *c c* cross rails framed between the trams, *d* the grinder's seat supported on a bracket, *e* an iron guard, which protects the grinder in the event of the stone breaking, and *f* the needles being ground.

It is proposed to protect the workman from the iron and grit-dust which he produces and inhales, by suspending from the ceiling of the grinding room a sheet of canvass, (painted or not,) which shall extend from wall to wall immediately over the axis of the stones. This canvass is to reach to the floor, and is to have two vertical cuts in it from the bottom upwards at each wheel, and the slip of canvass thus partially disengaged is to be turned upwards and made to fasten at various heights, either by a hook or button to accommodate the various diameters of the wheels which may be employed; *g g g' g'* represents the canvass, the line at *g' g'* pointing out a division in it by which the workman gets through to his work; this opening is afterwards secured by buttons or hooks; *h* is the slip cut out to admit the stone, turned up and buttoned at *h'*, leaving an opening about one inch and a half high over the stone, through which the iron and grit-dust is violently impelled by the centrifugal force, as described by the dotted lines *i*, fig. 6. The stream of dust generally maintains a state of brilliant ignition, and moves in the direction of the tangent with extreme velocity for at least twelve inches from the points of the needles; there is therefore no difficulty in conveying by far the larger portion of it into that part of the building separated from the workman by the canvass, and the current produced through the aperture by the revolution of the stone will effectually prevent its return. A few, however, of the lighter particles rise almost perpendicularly from the points of the needles, and these it is proposed to arrest by one or more rows of octangular magnets suspended nearly over the points of the needles, as *k k*, &c.; they may be fixed to a bar *l*, resting and capable of moving up and down on two uprights *m m*, supported either on the trams *b b*, or secured to the iron grate *e*. The canvass, besides the apertures already described, will require some cutting and adapting, to fit as nearly as possible the irregularities of the trams, &c.; but all this will be quite obvious and must depend on the particular construction of the mill to which it is applied. A wooden partition might be used with perfect success instead of the canvass but

Mechanical
Processes.

Dry grind-
ing.

Pl. lxviii.
Fig. 6, 7, 8.

Manufac-
tures.

from the circumstance that the trams and stones are moved forward, as the bands which impel them are shortened by rejoining after having broken, and the pliability of the canvass screen renders it peculiarly fitted for adapting itself to this change of place; but a slight attention to the mode of uniting the bands would make a wooden partition perfectly applicable.

The apparatus described in the engraving has been partially used at Redditch, and, as the testimonials show, has been proved to be effectual. The principal difficulties which oppose its general and successful adoption arise from the nature of the buildings in which the work is performed, and from the habits of the men employed in them. In a building about twenty feet long, not so many high, and nine or ten feet wide, from six to nine men work; they are placed on three stages or shelves about six or seven feet wide, occupying one end of the building; the other end contains the machinery. The men sit close to the end of the wall, and are essentially all in one room, or rather worse than they would be in one room where all worked on the same floor, for the stages are scarcely far enough apart to allow a man to stand upright, and the dust falls through the joints from one to another. These grinding houses are sometimes built in pairs, and in consequence of this a strong side wind, which would otherwise be useful, merely blows the dust from the windward to the leeward house. Added to all this, the use of water as a power acting on overshot wheels occasions the mills to be erected in situations where they are shut up on three sides by banks nearly as high as their roofs. The result of the whole is, that the air is nearly stagnant, that the immense quantity of iron and grit dust hourly produced rolls slowly about the rooms till the atmosphere has become so fully impregnated that the men are scarcely visible on entering at the door; it then begins to be deposited on the floors and timbers, from which it is again disturbed by the motion of the machinery. On each side of the building, in a line with the axles of the wheels, are windows which it is impossible to close in the severest weather, and it frequently happens that the water in which the needles are dipped will freeze on the hands of the workmen. It will be requisite, therefore, for the full success of Mr. Abraham's contrivances that a greater space be left between the workmen and the wall behind, otherwise the canvass partition confines them in a space so small that in summer it attains a temperature almost suffocating. It will also be advantageous that the window be divided into two portions, the division corresponding with the canvass partition. The part next the workmen should have a glazed casement, to be shut when the weather requires it, while the other part might be permanently open.

Although it is true that some of the pointing mills are not subjected to all the defects of construction and situation which have been enumerated, they are without any exception confined in space and ill ventilated. It will be evident, therefore, that the complete reformation of the mischief must depend upon measures to be taken by the larger needle-makers themselves. The benevolent and persevering exertions of Mr. Abraham must be seconded by them to have any sensible effect. If the early production of a lingering disease, and its consequence, a premature death, among a whole class of men, be evils worth remedying, there is no case which calls so loudly for interference as that of the needle

grinders'. Nor is the sacrifice of health and life the only nor perhaps the greatest evil. The workmen are necessarily allured to their pernicious employment by high wages, which produce their almost universal accompaniment, idle and dissolute habits. The excessive earnings of the needle pointers at Redditch maintain a succession of men who taint the whole neighbourhood with profligacy; who with the most perfect consciousness devote themselves to an early death for the sake of a life of idleness and debauchery; and who acquire such a callous indifference to the fate which they know awaits them, that their apprehensions are said to have been excited lest Mr. Abraham's invention should be successful enough to affect their wages.

The case of the dry grinders at Sheffield and other places, though not so appalling as that of the needle-grinders, is sufficiently bad. They work in rooms which are, generally speaking, much better ventilated, and under circumstances which admit of a very simple mode of preventing the dissipation of the dust in the air. Fig. 8 represents a section of a Sheffield grinder's wheel, in which *a* is the wheel which runs in a cast iron trough *b b*; the grinder sits on the block *c*, which lies on the edges of the trough, and holds the article to be ground at *d*, the stream of iron and grit-dust taking the direction *d e*. To retain this dust a piece of canvass *f f*, formed so as to embrace rather more than a quadrant of the wheel, is suspended from the board *g*, which lies loosely on the trough; the board is notched round the wheel, and over the opening three canes or hazel twigs *h h h* are bent, forming an arch to support a canvass hood. The board *g* is easily lifted from its place for the purpose of wetting the canvass, (which must be kept damp,) and is as easily returned when that is done. In this manner the whole of the dust is arrested by some part of the canvass, and being retained there by the moisture requires only to be occasionally shaken out. For further security, an arrangement of magnets may be fixed in a semicircular frame, and this frame may be placed at the opening into the canvass hood, or in any other place which the peculiar circumstances of the case might dictate to the workman. In addition to the radiant magnets, other intermediate ones may also be fixed on the face of the semicircle. In all these cases octagonal magnets are recommended in preference to round or square ones, because the particles of iron seem to obey the magnetic influence with more force at the angles of the bar than at its surface. The magnets should be forged of steel bars about a quarter of an inch square, the attractive power not appearing to reside above a tenth or an eighth of an inch within the surface.

For the protection of the workman against the small quantity of dust which, in spite of every precaution, will float about the rooms, and especially during the operation of raising the stone, when the ordinary apparatus will not apply, Mr. Abraham constructed a muzzle formed of a frame of wood, the upper and lower pieces made circular to fit the lips; on this are fixed two or three thicknesses of crape or muslin, and it is studded with sixteen magnets, which will arrest a considerable portion of the deleterious matter before it can reach the crape; to the upper part of the wooden frame is attached a bent wire, to which crape is fixed for the purpose of protecting the nostrils. The whole is fastened by two strings passing round the head and tying behind. It has also been found that a semicircular frame, but without feet, having the magnets only on the face, may be

Mechanical
Processes.

Other kinds
of dry
grinding.

Manufac-
tures.

worn round the neck with considerable advantage.—
Trans. Society Arts, vol. xl.

Pin-making.

Pin manu-
facture.

(958.) The manufacture of pins is carried on to a very considerable extent in this Country, not only for home consumption, but also for exportation, the English pin being greatly esteemed in all parts of the Continent. Pins formed of brass wire seem to have been unknown in England till about the middle of the XVth Century, before which time they were larger than the present pin and made of box wood, bone, ivory, and some few of silver. In 1543, however, the manufacture of brass pins had become sufficiently important to claim the attention of the Legislature, an Act having been passed in that year, by which it was enacted "that no person shall put to sale any pins, but only such as shall be double-headed and have the head soldered fast to the shank, the pins well smoothed, and the shank well sharpened." Gloucestershire is noted for the number of its pin manufactories. They were first introduced into that County in 1626, by John Tilsby, and it is said that at this time they employ 1500 hands, and send up to the metropolis upwards of £20,000 worth of pins annually. The wire as received at the manufactory is too large for being immediately formed into pins; therefore we may state that drawing the wire to its proper size for the different kinds of pins is the first operation. The wire being thus reduced to its proper dimensions is straightened, and subsequently cut in proper lengths, and again afterwards cut into smaller ones, each length being sufficient for making several pins. Each end of these pieces is pointed so as to be sharp enough for penetrating, without difficulty, through linen, paper, &c., by either men or boys, seated before two small grinding-stones or steel mills, turned by a wheel, either by means of machinery or by the hand. These stones or steel mills are used for making the rough points and for smoothing them, and therefore they are careful to turn the wire so as to render the points uniform and regular. The pin is afterwards cut off to the length that is wanted from each end, and the process is repeated till the whole of the length is pointed.

The manufacture of the head is performed by the following operations: a piece of wire suitable for heads is spun on another piece, whereby the inside wire occasions the upper wire to be hollow when drawn off; this is then in a state required for being cut into heads, which is done by shears, every two rounds of the wire making a single head. The next process is that of heading the lengths; this is done by the operators or work-people taking up a single length and thrusting it among the heads, thereby catching one on, and then immediately placing it under a heavy weight or hammer, when receiving the necessary blow it is made secure, and thus the pin is completed in the first state. After this it is to be blanchéd or whitened, which is accomplished by putting the pin in a copper containing tin and the lees of wine. When this is completed, the pin is in a state for sale.

One great point aimed at in the manufacture of pins has always been so to fix the head on the shank or shaft that it shall remain on firm; but very frequently this object is not attained, either the head will come off at the end, or will descend down the shaft, and in either case the pin becomes useless; to remedy this evil, several Patents have been taken out, either with a

view to a more firm attachment of the wire head, or to raise the head on the wire itself, of which the latter has been the most successful; a very great proportion of pins now in use being of this kind.

Mechanical
Processes.

With a view to the former object a Patent was taken out by Mr. Bundy in 1809, which is thus described. The operation is performed by means of a frame or stock made of metal, in which are fitted a pair of steel dies in the manner of those generally used in the manufacture of screws, held together by cylinders; the dimensions may be various, according to the quality of the work, but the dies most generally in use are about two inches long and one inch wide. In the prominent parts, and that side of each of the two dies which come in contact when in use, are made corresponding grooves, which when pressed together form holes, each to be the diameter of the shaft intended to have the head fixed on; these holes may be made tapering upwards, or contracted at that part close under the head, where half a hemisphere whose diameter is that of the size of the head required is to be worked out.

The dies thus worked are fixed in a particular kind of frame, and placed in the position in which they are while introducing the pointed shafts, each having a head loosely put on. The upper die being at liberty in the frame, the pressure of its weight will be found sufficient to hold the number of shafts with their heads in their respective places, while they are pushed forward with a straight motion till the quantity of the heads prevents the shafts from going any further. In this state it is necessary to turn a lever, to which is fixed a screw for the purpose of forcing the dies together, which holds the shafts firm enough to receive a stroke from a press on the top piece, to secure and form the whole number of heads in the dies. The hemispheres are finished according to fancy, as respects the ornament or figure of moulding intended for the top of the head, by sinking them accordingly. The patentee says, "I leave a point in the centre of those cavities in the top piece, which serves when forced into the top of the shaft to widen it there and form a rivet, and thereby secure the head firm from coming off the top of the shaft; and, the dies being hard screwed together with the lever, there will be a collar formed by that pressure on the shaft under the head sufficient to prevent the liability of the head being by any ordinary means forced down the shaft." Having described the working parts and explained the process by drawings, Mr. Bundy adds, that, placing the whole in a fly-press, one stroke therewith on the top piece will be found sufficient to complete the whole number of heads in the dies. "Hitherto," it is observed, "it has been the practice to strike the head several times, but my method of effectually and securely fastening the heads on the shafts and leaving the heads of a superior form, is by placing the shafts in a perpendicular direction, and striking the heads and shafts on the tops, which I call superior heads, and which method I claim as my invention. To succeed in the completest manner in forming these superior heads, it will be necessary that the dimensions of the heads before they are fixed to the shafts should be particularly attended to. If they are to be of nearly a spherical figure, they should be prepared of a greater depth of axis than the diameter, that the diameter may be small enough to go freely into the hemispheres in the dies and top piece which are to receive them; for this purpose, head wire may be made flat, either by drawing or rolling to a size

Manufac-
tures.

such that when spun one or more rounds will be sufficient for a head. I recommend head wire of a smaller size than ordinary without flattening, so that when spun and cut, three rounds of it shall contain the quantity of metal required for the size of the intended head. When the heads have been fixed on the shafts by the fly-press, the screw is then to be turned back by a lever, and taking hold of the milled head, which is on the head of the small shaft, and which goes through the screw, and is fixed to the top dies by being screwed hard in the die, it may be drawn back to separate the dies sufficiently wide for the superior headed pins which they contain to fall through into some place prepared to receive them."

In 1824, a Patent was taken out by Mr. Wright of Wellclose-square, in which several improvements are proposed to be effected, *viz.*, first, in the method of supplying the wire for making the pins, and of straightening the wire as it advances; secondly, in the method of cutting the wire into suitable lengths for forming the pins; thirdly, in the method of carrying the wire so cut to be pointed and headed; fourthly, in the apparatus for pointing the wire; and, lastly, in the manner of forming or raising the head at one end thereof by means of two dies, by which the head of the pin is formed of a portion of the same piece of wire as the shaft or shank of the pin itself. The machinery and apparatus by which all these operations are performed are exceedingly ingenious, but they require too many figures for us to allow ourselves to describe them; we must, therefore, refer the curious reader to vol. liii. of the *Repertory of Arts*, where he will find the specification at length, with accurate engravings of the several machines, dies, &c. Whatever method or machinery is employed in forming the pin, it is when finished, as far as the making is concerned, still brass; it is then thrown into a copper containing a solution of tin and lees of wine, where it remains some time, but when taken out it assumes a white but very dull appearance; to give it a polish, it is put into a tub containing a quantity of bran, which is set in motion by turning a shaft that runs through its centre, and thus by means of friction it becomes perfectly bright. The pin being complete, it only remains to separate it from the bran, which is performed by a sort of winnowing, the bran flying off and leaving the pin behind.

Pins are sometimes made of iron wire, rendered black by a varnish of linseed oil with lamp black, which are designed for the dress of persons in mourning; they, however, are at present but little in use, having been superseded by steel pins rendered a deep purple by tempering.

A more general account of pin-making will be found in our Introduction.

Plating and Plated Goods.

Former
method of
plating.

(959.) The old method of plating was to apply thin silver leaves over brass articles after they were in other respects completely finished, and is still known by the term French plating; and some English manufactured goods, particularly those on steel, are plated in this manner; such, for example, as plated dessert knives and other articles for the table. Thus, for instance, the knife being first properly formed in steel, a piece of silver leaf is cut to cover the knife on each side; it is then placed for a short time at the entrance of the plating furnace, during which the union of the silver

and steel is completely effected, and it only remains to give to it its proper burnish. With brass goods the polishing is first produced on the original article, they are then rendered free from grease and every other extraneous matter, and the part to be plated is heated to a temperature just below that which causes a change of colour in the metal, leaf-silver is then laid upon the part, and while hot is rubbed with a steel burnisher perfectly dry and clean. By this means the silver was made to adhere to the brass, which from the action of the burnisher assumed a fine polish. The goods thus plated differ but little in appearance from those plated according to the present method, but they possess less permanency, and this old practice is almost entirely laid aside by English platers, except in the cases above referred to.

Mechanical
Processes.

According to the present practice, the metal is first produced in sheets plated on one or both sides, and the goods are manufactured at once in the plated form. The first process consists in casting an ingot of alloy of copper and brass, generally about one and one-eighth of an inch in thickness, three inches broad and eighteen inches long. Great precaution is required in this process to obtain a very perfect ingot, for any holes or other imperfections will produce a general defect in the plate after rolling. The ingot is cast in cast-iron moulds, having rising mouth-pieces to give a certain pressure to the metal, and to allow any impurities to rise above the general surface, and considerable skill is required to have the heat of the mould and that of the metal properly adjusted.

Modern
method of
plating.

The ingot being thus formed is next to be plated, in order to which the face of it must be very carefully dressed with a file till it is entirely free from any unevenness or imperfection. When the plate is to be silvered on both sides, these must of course be both dressed in the same manner; the former is called single, the latter double plating, and in both cases the greatest accuracy is required, such indeed that either surface will bear to be examined by a considerable magnifying power without exhibiting imperfection. The thickness of the silver to be laid upon the copper is generally such that its weight is about one-twenty-fourth or one-thirtieth that of the copper, and of course about one-twelfth or one-fifteenth when plated on both sides, the proportional thickness of the two metals varying in the single plating from one-thirty-sixth to one-fortieth.

The plate of silver is cut a little less than the size of the copper surface, made flat, and scraped perfectly clean; the copper surface being equally clean they are laid together, and the silver plate is tied down with wire. A little saturated solution of borax is now introduced under the edge of the silver plate on every side, which fuses at a low red heat and prevents the oxygen of the atmosphere from affecting the surface of the copper, which would injure the adhesion of the silver, and in this state the ingot is brought to the plating furnace. This has a grate on a level with the bottom of the door; the fuel consists of coke, and the ingot is laid on the coke and the door shut. When the ingot has attained nearly a proper heat, the plater watches the process carefully through a hole in the furnace door, and knowing by certain signs when the proper state is attained, it is quickly removed; for, if allowed to remain longer, the silver would become alloyed with the copper and the plate spoiled as far as relates to its intended purpose. In this process the silver is, in fact, soldered to the copper,

Manufac-
tures.

although no solder is expressly employed. It is well known to chemists that an alloy of silver and copper, as well as many other alloys, is more fusible than either of the simple metals; and, from what takes place in the above process, it will be easily inferred that a portion of silver and copper unite at the contiguous surfaces, which, fusing before the silver or the copper, unites the former with the latter. The ingot being now plated is made perfectly clean, and is ready to be rolled. The first rollers employed for plated metal are of cast iron, similar in size and construction to those employed for sheet iron and sheet copper. The metal is rolled cold and annealed from time to time; when it has gone through the rollers a certain number of times, it acquires such a degree of hardness that the rollers have not much effect, and if the rolling were continued the metal would crack. This is an evil which must be remedied by taking the metal to a reverberatory furnace; where it is laid upon a hearth of brick or fire-stone, and the flame of coal made to pass over it, but, since the metal is required to be slowly brought to a dull red, the heat is not intense. It may now be cooled in the quickest way possible to save time, as quenching in water does not affect it as is the case with steel; it is now passed through rollers as before till it becomes hard, and then annealed and rolled again till it is reduced something short of the size required; this being done, it is again annealed and passed through a pair of rollers faced with cased steel and finely polished, which gives the surface great smoothness and truth. It is now annealed for the last time, and the sheets, after having been immersed in hot dilute sulphuric acid, are then scoured with fine Calais sand, which fits them for the workman to shape into different articles.

The pieces of metal to be plated for the purpose of making wire are forged out of bar copper unalloyed, which pieces are of a cylindrical shape, about eighteen or twenty inches long, and about one and a quarter inch in diameter. The true cylindrical shape is given to the copper by wiredrawing; it is then made perfectly clean and metallic by scraping, but the silver to be laid upon it is much thinner in proportion to the copper than was stated in the sheet metal; the silver is first formed into a tube, one edge projecting a little over the other, and the copper cylinder is a little less in diameter than the tube, and so much longer as to admit one end to project. The tube is now slipped upon it with the seam upwards, and a steel burnisher, with rounded polished edges and a handle at each end, is rubbed briskly backwards and forwards upon the over-lapped edges of silver, at the same time using considerable pressure; by this means the surfaces are completely welded together, so that it would be difficult to find where the union had taken place. The cylinder of copper intended to be plated is made perfectly clean; the same caution is necessary for the inside of the silver tube; it is now to be put upon the cylinder, which is about two inches longer than the tube; there is a small groove made round the cylinders coinciding with the ends of the silver tube; into this groove the ends of the tube are closely worked so as to render the space between the tube and the cylinder perfectly air tight. The necessity of this is obvious, since the whole is required to be heated red hot, which would cause the oxidation of the copper and prevent the silver from adhering to it. When the cylinder and tube are together heated slightly red hot, the same burnisher used for uniting the tube is

now rubbed briskly over the tube in a longitudinal direction. This unites the silver firmly to the copper, and makes it fit for drawing into wire of various forms and sizes: the machine employed for drawing this wire is precisely similar to that used for brass and copper wire. The great variety of figure and form given to it depends upon the plate through which it is drawn, some of which are flat, half round, fluted, or with mouldings; it is chiefly used for making bread-baskets, toast-racks, snuff-boxes, and many other articles requiring much neatness and elegance with little manual labour. The wire after drawing, like sheets after rolling, is annealed, and afterwards cleaned with hot dilute sulphuric acid.

(960.) The plate and wire being prepared as above described, we come now to the manufacture of the plated articles, which resemble in a great measure that of thin copper articles, but being commonly of a lighter description admit of and require more delicate processes. The workers in plated goods are termed braziers, candlestick-makers, and pierce-makers; the former being employed in making the larger articles, the second in making candlesticks and similar goods, and the latter the open work, such as bread-baskets, tea-trays, &c. Formerly all the different shaped vessels were made with the hammer, but at present all but the very largest are raised or sunk by the stamping hammer, except, indeed, some of the smaller parts, as in the forming of candlesticks, &c., and these are formed by a lathe, the pattern attached to the mandril being of the intended form of the part. A circular plate of the metal of the proper size being placed on the front of the mandril, the workman applies to it a hard wooden tool and, pressing it back upon the mandril, at length brings out the form and figure of the part required. By much the larger proportion of goods, however, are raised by the stamping hammer. This consists of a large stone base on which is secured an iron anvil, and to the latter the die containing the figure of the intended article is fixed by four screws; see fig. 9, 10, plate lxviii. The manner of working the hammer is by the workman placing his foot in the stirrup shown in fig. 10, and seizing at the same time the rope with his hand; the weight by the action of both is raised to the proper height, and is then left to descend with its whole force. The figures require but little description: *a, a*, fig. 9, are two upright square pillars with the angles opposed to each other, which work in angular recesses in the hammer *d*, which admits the latter to work freely and truly from top to bottom, the weight being first raised by pulling on the rope as above described.

All moderate-sized vessels are raised in this manner, but the larger kind by the hand hammer, and those which are of less diameter at the top and bottom than in the middle must necessarily be either raised by hand or stamped in two pieces, and afterwards soldered in the middle. The dies should be made of cast steel, but it should be in such state as to weld with iron, so that the iron should not be much below the surface of the die; this is more particularly requisite when the die is to be hardened; in other cases the whole die may be of cast steel. The die being placed on the anvil, and the metal cut into pieces of proper size, the top of the die is surrounded with a paste made of oil and clay an inch or two above the surface, and into this cavity is poured a proper quantity of melted lead, which of course receives an impression of the die reversed. The under side of the stamping hammer has a flat face of iron fitted into it, about the breadth and length of the die, which is

Mechanical
Processes.

Modes of
manufac-
ture.
Pl. lxviii.
Fig. 9, 10.

Stamping
hammer.

Description
of the dies.

Manufac-
tures.

called the *licker-up*, and when the lead becomes solid, the hammer is raised to a certain height and let fall upon it; the under side of the piece of iron above named being cut on the surface into teeth, in shape like those of a rasp, firmly adheres to the lead, and the latter is then raised with the hammer. The metal to be stamped is now placed over the die, and the hammer with the lead is made to fall on it till the impression is completed. If, however, the vessel is of any considerable depth, two or three dies are used, one bigger than another, the last being the proper size and shape of the vessel.

This process of stamping hammer and dies is employed in forming not only plated vessels, but also livery buttons and medals; many beautiful specimens of the latter kind are exhibited at Sir E. Tomason's manufactory at Birmingham, where the process above described is shown to any stranger having permission to view the establishment.

Cylindrical and conical vessels are mostly formed by bending and soldering: the bending is performed on blocks of wood with wooden hammers, and in the smaller articles, such as the ornamental parts of candlesticks, it is done on a mandril, as has been already stated, the several successive parts forming the entire candlestick being soldered to each other, the number of such pieces in the most ornamented articles of this kind amounting to upwards of thirty. The ornamental beadings and mouldings, seen in many plated articles, are formed by passing strips of the metal through rollers fluted to form different patterns, or by means of what are called swages, by which the metal is made to take up its proper figure.

Silver
edges.

A very great improvement in the manufacture of all plated goods is the introduction of silver edges, beads, and mouldings, for before this means of defending the prominent parts was introduced, the article soon became naked of plating in those parts, and the nature of the interior was discovered, and consequently its beauty destroyed; but by this practice the edges, beads, and prominent parts will now remain perfect longer than the more protected plated divisions. The silver employed for this purpose is rolled extremely thin, a superficial inch sometimes not weighing more than ten or twelve grains. This is of course too delicate to have its ornamental figures given by the processes above described for beads and mouldings, it is therefore done by lead and dies as described in stamping, but of course by more gentle means.

When these silver mouldings are formed, and the refuse metal is removed, they are laid upon a level plate with the hollow side uppermost, and small pieces of rosin are put into the hollow parts and soft solder melted in with the soldering iron. To prevent the solder adhering accidentally to the outer surface, it is previously covered with a composition of size and whitening of about the consistence of paint; the solder, which is very soft, is composed of equal parts of lead and tin. The silver shells thus filled with soft solder will now admit of being bent into almost any form, and after they are accurately fitted to the place they are intended to occupy, the part being first made clean and partially tinned, they only require to be secured by temporary fastenings till the parts can be exposed to a degree of heat capable of melting the solder.

When the different plated goods come from the hands of the workman, the metal, although clean, is of a dull white colour, possessing no polish whatever. The last

finish has therefore still to be given, and is generally performed by women in separate apartments. The bur-
nishing tools are generally blood stone, but some are of
hardened steel finely polished. The latter are for bur-
nishing the minute parts which cannot be touched with
the blood stones, these being commonly used only on
the larger and more open parts.

Mechanical
Processes.

Small Shot Manufacture.

(961.) This, like most other mechanical processes, has undergone considerable alteration within a short time. The general process consists in melting the lead, and after stirring and taking the scum from its surface, throwing upon the the same a certain quantity of powdered yellow orpiment, then the whole being well stirred the orpiment will flame, and to now judge whether he metal is in a proper state it is tested by dropping a little of it into a glass of water, and if the particles or shot turn out to be round and without tails it is in a proper state, if not more orpiment must be added. The next process is to take a copper plate hollowed towards the middle, punched through with several holes according to the size of the intended shot, which is placed in a frame over a vessel of water. This plate is kept to a proper temperature by means which differ in different manufactories, and on the plate is poured a certain quantity of melted lead, which makes its way through the holes in the bottom and falls into the water in round drops. The shot thus made are dried over a gentle fire, always stirring them to prevent their melting and adhering together; they are then sorted according to their different sizes, and put up in separate bags, differently numbered, for sale. The uniformity in the figure of the shot is greatly promoted by lengthening the fall of the drops, which in some modern establishments is very considerable, whereas in the old method the lead did not fall more than a few inches.

Tinning.

(962.) The affinity which has place between tin and
some other metals, particularly iron, copper, and brass,
renders the process of tinning a subject of considerable
importance in the Arts and Manufactures of this Coun-
try. Iron is a metal greatly disposed to oxidation, but
by being covered with a thin coating of tin its surface
is preserved from the action of the atmosphere, and the
articles formed of it are greatly preserved, particularly
those used for culinary purposes. Again, copper and
brass, when thus employed, are liable to oxidation, not so
injurious to the metal, perhaps, as dangerous from their
poisonous effects to individuals, which are supposed
also to be prevented by a slight coating of tin given to
the inside of the vessels.

Tinning.

Tinning iron plates.—The art and practice of tin-
ning thin iron plates was derived by us from the
Germans, being very little known in England till the
early part of the last century, when the attention of the
English artists was called to the subject by Mr. Rutty,
in a Paper published in the *Philosophical Transactions*
for 1725. An attempt had certainly been made in 1681
to introduce the practice by Andrew Yarranton, which,
however, failed; but the former was more successful,
and the Art is now perhaps better known and more skill-
fully executed in this Country than in any other, and it
is moreover carried on to such extent as to render it an
important branch of English manufacture.

Tinning
iron plates.

Manufac-
tures.

French
process.

Although the processes described by Mr. Rutty are now in many respects changed, his description will not on that account be less interesting to the curious reader. The author observes, that the making of tin plates, called in France *fer blanc*, or white iron, properly begins with preparing the leaves or plates of iron to be tinned which are supposed to be sufficiently thin and flat and cut into squares; but those are the most proper which, when heated, are easily extensible and yet can be forged with the hammer, the most soft and extremely flexible, as well as the more brittle, being rejected. These leaves are drawn from bars of iron about an inch square, which being made a little flat are cut into thin pieces, then folded together, and being made into parcels containing forty leaves each, are beaten all at once with a hammer of 600 to 700 pounds weight. After this the principal part of the whole Art is to prepare these leaves, for the lightest dust or the least rust on their surface will prevent the tin from uniting with them. This is taken off by steeping the plates in acid waters for a certain time, and then scouring them with sand. By this method a woman may clean more plates in an hour than the most expeditious workman can file in many days.

Of these waters the author mentions several, but what the Germans themselves used, and which they made a great secret of, he found to be only common water made slightly acid with rye, which requires very little pains; for after they have ground the grain roughly and pounded it, they leave it to ferment in common water for a certain time, and with a little patience they are sure to have an acid menstruum. With this they fill troughs or tuns into which they put piles of plates; and to produce the acidity the better and to have more activity, the vessels are kept in vaults or stoves which have little air, and in which lighted charcoal is kept. The workmen go into these vaults once or twice a day, either to turn the plates that they may be equally exposed to the action of the acid liquor, or to take out those that are sufficiently cleansed, or to put others into their place; and as the liquor is more acid, or the heat of the vault or stove is more intense, the plates are sooner cleansed, but this process requires at least two days, and sometimes a great deal more.

This is the method which the Germans, employed in the tin-works in France, made use of, to prepare the iron plates to receive the coat of tin; but, as the author observed that the constant attendance on them in the stoves was very laborious, the heat therein being almost insupportable to those who are not used to it, he proposes some other methods which are attended with very little trouble, and as small, if not a less, expense, and which on trial succeeded full as well. Having, therefore, observed that the iron leaves or plates are covered with scale or layer, half vitrified by the fire, on which acids have none or very little effect, he imagined that, instead of dissolving the iron in these acid waters, it would be better to make it rust and thereby put it in a condition to be easier cleansed from these scales; as rust is accompanied with a sort of fermentation and rarefaction, and the matter which rusts takes up a greater space and raises up whatever opposes it. To this purpose he steeped iron plates in different acid menstrooms, as in water in which alum, common salt, and sal ammoniac were separately dissolved, and others of the same iron he only dipped into the same waters, and instantly taking them out exposed them to

the air. These latter were rusted by all of them, but sooner by that in which the sal-ammoniac was dissolved. After two days, during which every plate had been dipped into the menstruum but twice or thrice, he scoured them and likewise those he had left to steep for that time, and, comparing them together, found that those which had been only wetted at different times cleansed better than those which were steeped, the rust covering all the surface of the latter without raising the scale, whereas in the former, as soon as one part of the metal is detached, it is attracted by the menstruum and the surface is raised into blisters of rust.

These dissolvents, the author observes, though weak in themselves, yet produce the effect as well as the stronger, which are much dearer; but among the latter he prefers vinegar, which, being very plentiful in France, may be used with little cost, for it is only necessary to dip each leaf into it and take it out again immediately; leaving it afterwards in some moist place, it will be scaled in forty-eight hours, if care be taken to repeat this three or four times a day. The scaling will be still more expeditious by dissolving a little sal-ammoniac in the vinegar, a pound or two to a puncheon, for as the vinegar dissolves iron well, so sal-ammoniac rusts it sooner than any other salt; but this must be used very moderately, and the leaf must be left to steep in clean water, to dissolve any particles of it that may stick to its surface, which may otherwise make it rust after it is tinned. If vinegar is used for scaling, and it should be desirable to do it at a less expense, it is only necessary to plunge the leaves once or twice at furthest, and when the vinegar is dried on the surface, it should either be sprinkled with water or the leaves dipped into it and taken out immediately. There are several other ways of making iron rust; as keeping it in a moist cellar, exposing it to the dew, sprinkling it with common water several times in a day, which will still act quicker by dissolving sal-ammoniac in it. In those Countries where pyrites are common, the vitriolic waters will scale them soon enough, which are almost as cheap as common water; it is only necessary to heap pyrites together and to leave them to moulder in the air, and to make afterwards a lixivium with them and common water, which, forming a lie, will have the desired effect. But as the leaves of iron are much more easily cleansed on one side than on the other, the bad side rarely taking the brilliant polish in the tinning, but having always some spots, which happens because in the beating, one side is more exposed to the action of the hammer and is therefore better plained, the author again advises not to steep them, but only to moisten them in order to make them rust, moistening that side only that wants it most; whereas if they are steeped, as the bad side will take double or triple the time of the other, the acid menstruum will dissolve the surface and occasion a loss of iron. He next gives two cautions necessary to be followed: the first is in the management of the plates before they come to be prepared, which is, in the beating of them, to change the place of each in its turn that every one may receive the immediate action of the hammer, otherwise they will not extend; the second is to steep them in clay or fuller's earth tempered with water, before beating them, to prevent their soldering with each other. He then closes this part of the operation with remarking that, whichever of these methods is adopted, whether the old one, of which he has learned the secret, or any of the new, which he has here shown, it is absolutely necessary

Mechanical
Processes.

Manufac-
tures.

after the plates are sufficiently scaled to scour them with sand, and when no more black spots remain on their surface to throw them into water to prevent their rusting again, and leave them in it till the instant they are to be tinned or blanched, as it is called. This, he observes, is the very object of the whole Art, and is kept as much a secret by the blancher as the acid corroding menstruum is by the scalers; but the manner of doing it is thus: they flux the tin in a large iron crucible which has the figure of a pyramid frustum with four faces, of which the two opposite ones are less than the others. This crucible they heat only from below, its upper border being luted in the furnace quite round. The depth of the crucible always exceeds the length of the plates to be tinned, which are always put in downright, and the tin ought to swim over them.

For this purpose, artificers of various trades prepare the plates in different manners, which are all exceptionable; but the Germans, he perceived, made use of no preparation whatever, except putting the scouring plates into clean water as just remarked, but when the tin is melted in the crucible it is covered with a layer of a sort of suet an inch or two thick, through which the plate must pass before it comes to the tin, the first use of which is to keep the tin from burning, and if any part should take fire, as the suet will soon moisten it, to reduce it to its natural state again. This suet is a composition, as the blanchers say, and is of a black colour, which the author thought might be given it with soot or the smoke of a chimney, only to spread a mystery over their work; but he found it true so far, that common unprepared suet was not sufficient, for after several attempts there was always something wanting to render the success of the operation certain. The whole secret, then, of blanching lies entirely in the preparation of this suet; and this he at last discovered to consist only in first frying and burning it, which not only gives it the colour, but puts it into a condition to give the iron a disposition to be tinned, which it does very successfully.

The tin itself ought to have a certain degree of heat, for if it be not hot enough, it will not adhere to the iron, if too hot, it will cover it with too thin a coat, and the plates will have several colours, as a mixture of red, blue, and yellow, and the whole will appear of a bad yellow cast. To prevent this, by knowing when the tin has a proper degree of heat, they might first make an essay with small pieces of the scaled plates, their appearance would show when the tin was in proper order; but, generally speaking, the plates are dipped into tin that is more or less hot, according to the thickness the coat is required to be. Some plates only require one layer, these are plunged into tin that has a less degree of heat than that in which those plates are dipped which are to have two layers; when the second layer is given, they are put into tin that has not so great a degree of heat as that into which they were put the first time, besides which, it is to be observed that the tin, which is to give the second coat, ought to be fresh covered with suet, but only with the common sort without preparation; for melted tin is sufficiently disposed to attach itself to solid tin, and in this case it is to tin itself to which the new tin is to be joined. *Philosophical Transactions*, 1725.

Process in
England
and Wales.

(963.) The present process as carried on in South Wales is described by Mr. Donovan in his *Descriptive Excursions through South Wales* in 1805, and it differs

but little from the operation which the author has seen in Staffordshire and in other Counties. Mechanical Processes.

The iron ore employed in this manufacture is the common kind of the country, intermixed with a large portion of the fine hæmatite from Ulverstone in Lancashire, which gives a very fine metal. This too is smelted with charcoal instead of coke, to produce a metal of the greatest purity and extensibility and closeness of texture, which qualities are particularly required in this manufacture. The reduced ore is smelted in the usual manner and cast into pigs, which are then wrought by the hammer into long flat bars, that are afterwards cut into pieces of about ten inches in length. These are then wrought into plates by being heated red hot, and passed through a flattening-mill, which consists of two large cylinders of steel, casehardened, and secured in a frame of iron. These are placed contiguously to each other, but with a certain interval of space, and revolve in a contrary direction, so that when one end of the bar is thrust in the space between the cylinders, the whole is drawn through and proportionably extended and flattened in the passage. The distance between the cylinders, which of course determines the thickness of the plate, is maintained and regulated by screws which can be altered at pleasure. When the bar is thus made into a plate of twice the thickness of the ordinary plates, it is heated red hot, cut in two by a pair of shears and one piece folded exactly over the other, and both repassed repeatedly through the cylinders till the folded plate has extended to the same length and breadth as the plate was before cutting. It is then clipped round the edges and the two plates are torn asunder, (which requires some little force,) after which they are finished by passing through a finer rolling-press, so as to take away every increase or inequality in the plate; and those that are too rough to pass through this finer press are thrown aside.

The plates are then steeped in a very weak acid liquor, and when taken out are scoured thoroughly with bran, so as to be quite bright and polished to enable the tin to adhere. The tin is melted in deep rectangular crucibles, and kept fluid by a moderate charcoal fire beneath. To prevent its calcination, a quantity of grease prepared from lintseed oil and suet is constantly kept floating on the surface of the tin, and renewed as it evaporates off, which gives an excessive nauseous stench. The plate is then taken up by one corner with a pair of pincers, and dipped vertically into the tin, and when withdrawn is found beautifully white and resplendent with the coating of this metal that adheres to it. This dipping is repeated three times for what is called *single tin plate*, and six times for the *double plate*. The plates are then cleansed and sorted, and are fit for use.

The following process is for tinning without acids, a recent French Patent.

(964.) The iron plates, flattened or hammered, are scoured and cleansed in a large wooden vessel containing ten pounds of rye-flour to one hundred pounds of water: it is left to ferment until the scaly portion which is found upon the surface of the plate has wholly separated; that being accomplished, a bath of the tinning material is prepared in the following manner. To eighty pounds of fine tin are added twelve pounds of beef and as many of mutton fat, which latter are previously melted in a copper till the whole twenty-four pounds are reduced to half their weight; this is poured into the melted tin, after which half an ounce of fine silver is added and the whole is melted together. Tinning without acids.

Manufactures.

The mode of tinning.—The scoured sheets are dipped into a solution of half an ounce of sal-ammoniac to three pounds of water, after which they are plunged quickly and frequently into the bath of tinning composition already prepared in the caldron, care being taken to scrape the places not perfectly tinned: after these precautions, the sheets are drained and dried, having been previously shaken for the purpose of cleaning off the superabundant composition which would otherwise cling to the edges and ends of the sheets of pipe. The above composition is of tried solidity, and may be easily extended over surfaces of any length.

The length of the iron sheets intended for tinning may be seven feet, and the width in any proportion: with regard to pipes of the same length in a single piece, they may be soldered with copper, a far more solid soldering than brass, and which does not make any thickness or ridge.

Tinning tacks, nails, &c.

(965.) *Tinning tacks, nails, and other small articles.*—The workman having previously made the surfaces of the articles clean from rust or other oxide by pickling them, or putting them into sulphuric, muriatic, or nitric acid, diluted with water, as usual, and washing them well afterwards in water, he puts them in a stone gallon bottle, having an oval body, a narrow neck, and a handle to lift it by, together with a proportionate quantity of grain tin and of sal-ammoniac. He then places the vessel, lying upon its side, over a charcoal fire made upon a forge hearth and heats it, continually turning it round all the while, and frequently shaking it to distribute the tin uniformly over the surfaces of the articles to be tinned. They are then thrown into water to wash away all remains of the sal-ammoniac, and finally dried in saw-dust made warm.

The great merit of this process consists in the employment of the *stoneware vessel*, which not only prevents the dissipation of the sal-ammoniac in fumes, but also gives up the whole of the tin to the articles to be tinned, which would not be the case were a metallic vessel to be used.

Wiredrawing.

History of Art.

(966.) This very ingenious process, according to Beckmann, had its origin some time in the XIVth Century, prior to which time all the wire that was used was probably produced by means of the hammer, anvil, and file, of which he gives several instances. Our business here is, however, only with wiredrawing, by means of iron or steel plates, an Art which was first apparently introduced into Germany about the middle of the XIVth Century, for Beckmann observes that before that time the manufacturers of wire were called wire-smiths, but afterwards wire-drawers or wire-millers. Beckmann is much enraptured with the Art of wiredrawing; he observes that the greatest improvement ever made in this Art was undoubtedly the invention of the large drawing machine driven by water, and in which the axletree, by means of a lever, moves a pair of pincers that open as they fall against the drawing plate, lay hold of the wire which is guided through a hole in the plate, shut as they are drawn back, and in that manner pull the wire along with them. What a pity, he exclaims, that neither the inventor, nor the time when the machine was invented, is known! it is however more than probable that it was first constructed at Nuremberg, by a person named Rudolf, who long kept it a secret, and by these

means acquired a considerable fortune. Conrade Celter, who wrote about the year 1471, is the only author known at present who confirms this information; and he tells us that the son of the inventor, seduced by avaricious people, discovered to them the whole secret of the machinery, which so incensed the father that he would have put him to death had he not saved himself by flight.

Mechanical Processes.

"This Art," the author further observes, "was brought to great perfection at Nuremberg. Several improvements were from time to time found out by different persons who turned them to their advantage, and who received exclusive Patents for using them, sometimes from the Emperor, and sometimes from the council, which gave occasion for many tedious lawsuits." We have, however, reason to believe that the finer kinds of work, particularly in gold and silver, were carried on with great success above all in France and Italy, and that many improvements were brought from these Countries to Germany. In another part it is stated that all the wire manufactured in England, till the year 1565, was hand drawn, and that the art of employing mills was about that time introduced by foreigners. "Before that time the English wire was bad, and the greater part of the iron wire used in the Kingdom, as well as the instruments employed by the woolcombers, was brought from foreign Countries. According to some accounts, however, this Art was carried to England at a much later period, for we are told the first wire-making was established at Esher by J. Mommer and D. Demetrius; and Anderson says that a Dutchman constructed at Sheen, near Richmond, in 1663, the first flatting-mill ever seen in England."

At all events the Art of wiredrawing has since been carried to a great degree of perfection in England, particularly that part of it which is employed in the manufactures. Of this an immense quantity is used in card-making for the woollen and cloth manufactures; we have mentioned one establishment only, under Card-making, Mr. Dyers' of Manchester, in which more than thirty miles of wire is drawn and manufactured into cards every day, at least when the establishment is in complete operation. The French, however, appear still to be superior to the English in drawing the wires for piano-forte strings and other musical instruments.

(967.) The process commonly employed in this Country is exceedingly simple, the apparatus consisting only of a draw plate and draw bench. The draw plate is a thick plate of the finest steel perforated with holes of various sizes, from that of the largest to that of the smallest wire required. These holes are punched in the plate while hot, by well-pointed punches of German steel, four heats are generally required, and at every heat a finer punch is used, so as to make the hole taper, or take a slightly conical form; these holes are made to differ from each other by nearly imperceptible gradations.

Draw plate.

The draw bench is a simple machine, consisting of a horizontal roller or axis turned by four vertical levers like a rolling press, a strong chain or strap is coiled round the roller, and at the end of the strap is a pair of pincers for taking hold of the end of the piece of metal to be drawn; the draw plate is then made to bear against two strong iron pins placed in the draw bench, and the piece of metal being passed through the proper hole is seized by the pincers. By turning the levers the pincers at the end of the strap pull the piece of metal through the hole in the draw

Draw bench.

Manufac-
ture.

plate, and thus lengthen it a certain quantity; it is then drawn through smaller and smaller holes, being annealed when necessary, till it is reduced to the size required. This is a very general description, but it must be obvious that there is some difference between the early and the finishing process; in the former the wire is too stout to be coiled as it is passed through the plate, but in the latter stages it is as easily coiled as a thread of silk or cotton, and is so coiled in the English manufactures; in the former case the pincers are placed on a movable frame which recedes from the draw plate; moreover in this case seldom more than one wire is drawn at a time, but after it is reduced to the smaller size several such wires are drawn at the same time. The different coils to be drawn are placed on one side of the drawing frame or bench on reels; the ends are passed through the plates to the other side, where they are conducted to a cylinder or roller, which being made to revolve by steam, or other power, the process is continued with six, eight, or more wires till the reels are empty.

In wiredrawing much depends upon the annealing and other treatment of the wire; the smaller iron wire is previous to drawing immersed in a liquid formed of water and ale grounds, which is said greatly to facilitate the process; but we believe different manufacturers have different processes, which are not made public, and on which the character of the wire in some measure depends.

M. Pleyel's
Patent.

(968.) The following is the description of a process protected by a Patent for fifteen years for drawing wire for pianofortes and other musical instruments by M. Pleyel, an ingenious mechanic in Paris, and is thus described in vol. iv. of the *Repertory of Arts*.

"The white wires are made from soft and very ductile wire. The French iron wire best suited for this purpose are the kinds known under the name of *for de roche*. We employ in this manufacture only iron which has already been reduced into wire, at least to the dimension of two-thirds of a line in diameter. These wires owe their quality to the manner of tempering or annealing the iron wire, and of passing it through the draw plates.

"To anneal the wire, a fire-place is built of bricks and mortar, of a cylindrical form, having its exterior and interior edges furnished with an iron hoop beneath a large chimney. The dimensions of this fire-place or furnace are proportioned to the quantity of iron wire intended to be annealed at one time, which is placed in it upon an iron grate. This grate is placed so high as not to allow the fire to touch the wire. The furnace is covered with a sheet iron cover in which there is a hole for allowing the smoke to escape. The iron wire is placed in coils upon the grate till it reaches to about four inches of the top, the cover is put on, and a fire lighted with white wood only. The heat is kept up till the wire has acquired a pale red colour, and not more. That the fire may be distributed equally throughout, the cover should be frequently turned, because the hole in it would attract the heat, and without that precaution one side would be heated more than another. This method of annealing suits only iron wire of the size of one-third of a line in diameter; to draw it finer, the following process should be employed.

"In the furnace already mentioned, at a certain height above the grate, are supports on which another similar grate is placed. A strong plate of sheet iron is laid on each of these grates; the dimensions of the

plates allowing an inch all round for the passage of the ascending smoke, to allow the cylinder to fall from the top and to promote an equal communication of heat. The iron wire ought to be wound into a narrower space than the width of the plates of sheet iron, and placed on the lower plate in such quantity as to reach the upper one; the lower fire-place is filled with fuel, and the same combustible is placed on the upper plate; both fires are then lighted, the cover is put on and frequently turned during the process.

"In a furnace capable of holding fifty pounds of iron wire the fire is kept up for four or five hours, the length of time depending, however, on the situation of the furnace and consumption of fuel. The first process of annealing is commonly done twice on the same iron wire; the second is done after that wire has been drawn three or four times through the draw plates for reducing its diameter. The second process is employed but once.

(969.) "*Tools used in this manufacture.*—These tools consist of, first, a wooden work bench four or five feet long and three wide; secondly, a plank three feet long, one foot wide, and three inches thick, which is fixed to one of the edges of the bench by two pins. Above this plank two little barrels of wood are raised, ten inches in length and six in diameter, each having its axis placed in the direction of the width of the plank, and received in two brass supports, fixed firmly against the lateral sides of the same plank. The axis of each roller is furnished with a handle for moving it. At the middle of the plank there is raised, to the height of the centre of the axis of the barrels, a piece of wood of the whole width of the plank, in which is a groove four or five lines deep. At each extremity of this piece of wood two wooden uprights are framed, supporting a cross-piece in which is a second groove corresponding to the first. A draw plate is adjusted so as to slide easily between these two grooves. At each end of the same plank, and by the side of the draw plate, a small piece of hard wood is placed, on which the ends of the iron wire are filed before passing them through the plates.

"A sort of reel nearly like those used for thread, excepting that it is conical, serves to receive the rings of iron wire intended to be drawn. The bench serving as a foot for this reel is raised to the height of the barrels. On a small wooden upright, placed in a mortise made in the plank between the barrel and the draw plate, a little box is fixed, containing grease composed of lard and tallow. There is a hole through this box to allow the iron wire to pass through it and become smeared with the grease. To beat up the draw plate when the holes are too much worn, and to pierce it, we employ a block of wood similar to those intended for receiving small anvils, and on which a mortise is made sufficiently deep. A small file is used to reduce the end of the wire when beginning to draw; a pair of flat pincers for drawing it when introduced, into the holes of the draw plate; a common hammer and an iron gauge for measuring the sizes of wire; lastly, a draw plate is the most essential tool that we must have for this work. The material of which this tool is composed and the way in which it is pierced contribute very much to the quality of the wires.

"A draw plate, to be a good one, must be made of a substance neither too hard nor too soft, and those which are steeled are good for nothing, and pure iron is equally unsuitable. The best material for making them is a mixture of the best bar iron and cast iron,

Mechanical
Processes.

Tools used
in the
process.

Manufactures.

These plates should be pierced so that every hole goes on diminishing in diameter underneath; these holes are commenced with conical steel punches which are struck; the draw plate is then put to heat in a fire of only wood, and the operation of piercing it is afterwards completed when cold with steel punches. It is necessary to have punches corresponding to all the diameters of wires required to be drawn.

Manner of working.

(970.) "*Manner of working.*—When all the tools are ready, as above mentioned, and the iron wire also prepared, it is put upon a reel which is placed at the end of the bench. The end of the wire is then filed, pushed through the grease box, and into the hole of the draw plate corresponding to its size, and is drawn by hand with the pincers till it can be attached to the barrel, where it is fastened by points which are fixed for that purpose on the barrel, the barrel is then turned gently by means of its handle.

"For the first course it is necessary that the barrel which does not act should be removed, because it would be in the way of the wire coming off the reel to enter the draw plate. When the whole wire has passed through one hole, the other barrel is put into its place, the wire is sharpened anew, the draw plate is turned, the wire passed through the next following hole in size, drawn with the pincers, and fixed to the second barrel which is turned by its handle, so that the wire unwinds from the first barrel, passes through the draw plate, and winds on the second. It is necessary to take care that the wire be always passed through the grease box before entering the hole in the draw plate. One thing essential to be observed is that the wire passes through holes corresponding to its size so as to require but little power to pull it through, consequently the diameter of the wire is reduced but a very small quantity each time it passes through a hole in the plate.

"To draw wire of two-thirds of a line in diameter to one-third of a line, it is necessary to anneal it twice; brought to this size, it is annealed by the method before described, and afterwards it will not require annealing to be reduced to the greatest degree of fineness. In order that the iron wire may possess the proper degree of ductility and tenacity to form a sonorous string, it must pass five or six times through the draw plate after the last annealing. When the iron wire is reduced to the desired size, nothing more is requisite than to give it the necessary polish and white colour that it may render clear and distinct sounds.

Polishing.

"*Polishing and whitening of the wires.*—When the wire is drawn down to the proper size the draw plate and grease box are removed, the wire is fastened to the vacant barrel, and wound upon it, making it glide at the same time through a piece of leather previously rubbed on rotten stone. It is frequently necessary to repeat this operation to obtain a fine polish. The method of winding the wire on bobbins it is needless to describe. The size of the bobbins depends on the number desired to the pound weight.

Yellow wires.

"*Yellow Wires.*—The implements necessary for making these are the same as for the white wires, and they are used in the same manner, the only difference is in the polishing and annealing. To obtain good yellow wire we must employ only brass, (*mitraille jaune*), and three-tenths of calamine. This brass should be of a pure yellow colour; it may be procured at the manufactories in rods of a line in diameter. It is to be annealed once by heating it in the furnace, placing it on the grate, put-

ting white wood above and below it to obtain a clear and gentle fire. It is to be heated for an hour or two so as to be only red hot. On taking it out it should be dipped for a moment into a boiler of hot tallow. It is afterwards allowed to cool completely, and is then passed through the draw plate in the way already described for white wire.

Mechanical Processes.

"The brass wire is polished by the process before mentioned, excepting that instead of rotten stone we employ red tripoli; strings or wires made by these methods will stand in tune a tone and a half higher than the wires of Nuremberg." *Repertory of Arts*, No. 55.

MECHANICAL PROCESSES EMPLOYED IN THE MANUFACTURE OF FIBROUS MATERIALS.

Cotton Manufacture.

(971.) The extent and importance of the cotton manufactures of Great Britain, and the extraordinary increase which has taken place in them within a comparatively short period, naturally call for a more detailed account than we have been able to bestow upon other branches. The rapid extension of the cotton trade will be seen by a statement made by Edw. Baines, jun. Esq., in his excellent *History of the Cotton Manufactures in Great Britain*, i. e., that sixty years since our manufacturers consumed little more than 3,000,000 pounds of raw cotton annually, whereas the annual consumption now is 280,000,000 pounds. In 1750, the County of Lancaster, the chief seat of the trade, had a population of only 297,400, and in 1831 the number of its inhabitants was 1,336,854; and a similar increase has taken place in Lanarkshire, the principal seat of this manufacture in Scotland. The families supported by this trade are estimated by the same author to amount to 1,500,000 individuals, and the goods produced to furnish not only a large part of the clothing consumed in this Country, but also to supply nearly one-half of the immense export trade of Great Britain, finding their way into almost all the markets of the world.

Introductory remarks.

Early History of Cotton Manufactures.

Our object will be principally to illustrate the state of the cotton manufactures of Great Britain; but it will be interesting first to take a rapid sketch of its early history amongst other nations, and to trace it thence in its progress step by step, till it is found triumphantly established and extended in our own Country. There seems little doubt that the original birth-place of the cotton manufacture was in India, where it flourished long before the time to which any authentic history extends. That cloths made of wool, flax, or linen and silk, are of very ancient date, is sufficiently shown both by sacred and profane Historians, but in no one of these early Works have we any reference to goods manufactured from cotton, yet it is highly probable that cotton was woven in India as early as the earliest of the cloths above alluded to in Egypt. Herodotus, who wrote about the year 445 B. C., shows clearly that cotton was then and had probably been for ages the customary wear of the Indians; for in speaking of these people he says, they possessed a kind of plant which instead of fruit produces wool of a finer and better quality than that of sheep, of which the Indians make their cloths. If, then, Mr. Baines remarks,

Early history of the cotton manufactures.

Manufac-
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cottons were the common clothing of the people, it may with strong probability be inferred that they had been so for centuries, as the most striking characteristic of these people is their extreme indisposition to change; and it is to be remarked that Herodotus mentions this plant, and the manufacture produced from it, as peculiar to India; he makes no reference to vegetable wool being made into clothing elsewhere. Of the Babylonians he says distinctly, that their dress was of linen and wool, and that of the Egyptians of linen only, except that the priests wore a white woollen shawl when not engaged in their ministrations; it may, therefore, be concluded with certainty that at this time the cotton manufacture prevailed generally in India, and that it existed in no other Country West of the Indus.

We are led to the same conclusion by the statement of Nearchus, the Admiral employed to descend the Indus (327 B. C.) and to navigate the coast of Persia to the river Tigris. And from the interesting and obviously faithful narrative of this observant navigator, we learn that the Indians wore linen garments, the substance of which they were made growing on trees, which, he remarks, is indeed flax, or rather something much whiter and finer than flax. They wear shirts of the same which reach down to the middle of their legs, and veils which cover their heads and a great part of their shoulders; the name of the tree with the Indians, he says, was *tala*, and he describes its pods. Strabo also, who died A. D. 25, alludes to Indian cotton goods, and states that in his own time the cotton tree grew and cloths were manufactured from its produce in Susiana, a Province of Persia at the head of the Persian Gulf.

This valuable plant was now obviously advancing Westward, for in the time of Pliny, who lived about fifty years later than Strabo, the cotton plant was known in Upper Egypt, and also in the Island of Tylos, in the Persian Gulf. He says, "In Upper Egypt, towards Arabia, there grows a shrub, which some call *gossypium* and others *xylon*, from which the stuffs are made which we call *xylina*. It is small and bears a fruit resembling the filbert, within which is a downy wool which is spun into thread. There is nothing to be preferred to these stuffs for whiteness or softness, and beautiful cloths are made of them for the Priests of Egypt." The same author, in his description of the Island of Tylos, enumerates amongst its remarkable productions "wool-bearing trees, with leaves exactly like those of the vine but smaller, bearing a fruit like a gourd and of the size of a quince, which, bursting when it is ripe, displays a ball of downy wool, from which are made costly garments resembling linen."

We shall conclude this first period of our history of the cotton manufacture by a quotation from Mr. Baines's Work above mentioned, and to which we have been largely indebted for much valuable information.

"The first mention of cottons as an article of trade, is in that valuable record of ancient commerce, *The Circumnavigation of the Erythræan Sea, Periplus Maris Erythræi*, by Arrian, an Egyptian Greek, who lived in the Ist or IId Century of the Christian Era. This writer, who was himself a merchant and a navigator, sailed round the coasts of the Erythræan Sea, which comprehends that part of the ocean from the Red Sea to the furthest extremity of India; and he particularly describes the imports and exports of several Indian towns, in their trade with the Arabs and Greeks. From

this Work it appears that the Arab traders brought Indian cottons to Aduli, a port of the Red Sea; that the ports beyond the Red Sea had an established trade with Patala, (on the Indus,) Ariakè, and Barygaza, (the modern Baroche, on the great river Nerbuddah, near the North-Western coast of India,) and received from them, among other things, cotton goods of various kinds; that Barygaza exported largely the calicoes, muslins, and other cottons, both plain and ornamented with flowers, made in the Provinces of which this was the port, and in the interior and more remote Provinces of India; that Masalia (the modern Masulipatam) was then, as it has been ever since, famous for the manufacture of cotton piece goods; and that the muslins of Bengal were then, as at the present day, superior to all others, and received from the Greeks the name of *Gangitiki*, indicating that they were made on the borders of the Ganges.

"From the evidence of Strabo, Pliny, and the *Periplus*, quoted above, it appears that the growth and manufacture of cotton had, at the Christian Era, extended to Persia and Egypt, including muslins and calicoes, both plain and figured, which were brought by Greek navigators to the ports of Egypt and Arabia, whence, it may presumed, they would reach the Capital of the Roman world, and some of the wealthy cities of Greece. Yet cotton goods could not have been imported into Rome or Greece to any considerable extent, or even regularly, since there is no distinct mention of them as articles of importation or consumption by any of the writers of those Countries, though the other produce of the East, gold, spices, precious stones, and even silks, are often specified. The same conclusion is still more decisively drawn from the fact that the various kinds of cotton goods are not enumerated in the Roman law *De Publicanis et Vectigalibus*, which included the different articles of merchandise imported, with the duties chargeable upon them. But as a very extensive trading intercourse existed between Italy and Egypt, it is certain that cotton goods would have been imported into Italy if they had been largely manufactured in Egypt. It is probable that the use of cotton clothing was introduced very slowly in that Country, and did not become general for some centuries.

"To those who have observed the rapid spread of the cotton manufacture in the present generation, it may appear beyond measure extraordinary that a branch of industry so apt to propagate itself should have lingered thirteen hundred years on the coast of the Mediterranean before it crossed that sea into Greece or Italy. It may also appear remarkable, that the exquisite fabrics of India should not, when known, have been eagerly desired in the Roman Empire, and been largely imported. Such was the case with silks, which, though more costly, and fetched from the more remote region of China, were sought with avidity by the ladies of Rome, and still more by those of the Eastern Capital, Constantinople. Silk, both raw and manufactured, became an important article of commerce through India and Persia, and even by the route of the Oxus, the Caspian, and the Volga; and it is justly commemorated as an important event, that silk-worms, with the art of manufacturing their produce, were brought from China to Constantinople by two Persian Monks in the reign of Justinian, A. D. 552. It appears that Indian cotton goods were imported into the Eastern Empire in the same Age, as they are in the list of goods charged with duties in

Mechanical
Processes.

Manufac-
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Justinian's digest of the laws; but being scarcely mentioned by any writers, whilst silks are perpetually mentioned, it must be inferred that cottons were held in very subordinate estimation, and probably introduced only in small quantities. Left to conjecture to account for this fact, I can only suppose that the soft texture, glossy surface, and brilliant hues of silk, so different from woollen, linen, or cotton, and so much superior, captivated general admiration; and that muslins and chintzes could not vie with silks as articles of luxury, whilst they were too dear to compete with the manufactures of wool and flax as the materials of ordinary wear."

It would be inconsistent with the limited space within which we must confine the present historical sketch to extend our remarks to greater length respecting the progress of the cultivation of this plant, and the manufactures from it in different parts of Arabia, Africa, and Asia; it will be sufficient to state that, about the XIIIth Century, the use of it for clothing had become rather common with the Moors and Arabians, through whom it was introduced into Spain and Italy, its manufacture, however, being principally confined to the former Country.

The cotton
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tinent.

(972.) The next period in the history of cotton, both as regards its growth and manufacture, is connected with the discovery of America, where both the cotton tree was found cultivated and cotton cloths were richly manufactured. Cottons formed the principal article of clothing amongst the Mexicans, as they had neither hemp nor silk, nor had they wool except that of rabbits, and the flax which they did possess was not used by them for articles of clothing; their only materials for making cloths, besides cotton, were feathers, the wool of rabbits and hares, and a fibrous plant called the maguei. Amongst the presents sent by Cortes, the conqueror of Mexico, to the Emperor Charles V. were cotton mantles of various colours, waistcoats, handkerchiefs, counterpanes, tapestries, and carpets. The Mexicans also used cotton in making paper, and their warriors wore cuirasses of cotton which covered the body from the neck to the waist. Columbus also found the cotton-tree growing wild and in great abundance in Hispaniola and other West India islands, and on the Continent of South America, where the inhabitants wore cotton dresses and made their fishing-nets of the same material. When Magellan went out on his circumnavigation of the Globe in 1591, the Brazilians were accustomed to make their beds of this vegetable down, so that it cannot be doubted that the cotton as well as the indigo plant are indigenous in America as well as in India; their art of manufacture is also, in all probability, equally original, and it is impossible to say it is not as ancient.

Cultivation
in Europe.

With respect to the cultivation of the cotton plant, it has never made much progress in Europe, the climate generally being unsuited to it; it was, however, in the time of the Moors, introduced into Spain and has been cultivated in Italy. But henceforth our inquiries will apply principally to its manufacture and its general progress as an article of commerce.

Cotton
manufac-
tured in
Spain.

(973.) It appears that as early as the Xth Century cotton was manufactured in many parts of Spain, particularly in Cordova, Grenada, and Seville; and Barcelona, in the XIIIth Century, was celebrated for its cotton cloths; here the cotton was prepared and spun for the weaving of various stuffs used in those times, but principally for the manufacture of cotton sail-cloth, which was always a considerable branch of industry in that

mercantile city, which for more than five hundred years was the station of the Spanish squadrons. The same city was famous for its fustians, also a strong kind of fabric used to line garments, which derives its name from the Spanish word *fuste*, which signifies substance.

Mechanical
Processes.

The first record of the cotton manufacture in Italy does not seem to point to an earlier date than the beginning of the XIVth Century, and it is doubtful whether even then it was more than half cotton and half linen, the former constituting the weft and the latter the warp, as they were first made on their introduction into this Country; the same may also be said of the manufactures of Germany and Flanders, where they had, as is observed in the Work above quoted, "a lingering and ignoble existence." It would be altogether a mistake, it is further observed, to suppose that the same manufacture ever existed in any other part of Europe which now exists in England. A coarse and heavy article was indeed fabricated, probably half cotton and half linen, but it was of too little importance to attract the notice of historians; but calicoes, muslins, and the more delicate cotton goods were never made in Europe, except, possibly, by the Moors in the South of Spain, until the invention of the spinning machinery in England.

In Italy and
Germany.

(974.) There is some uncertainty respecting the time at which the cotton manufacture first found its way into this Country, or at least some misunderstanding formerly existed on this point, in consequence of the fabrics made at Manchester and some other towns in Lancashire being denominated for some reason cottons, which were actually woollen or linen. How this misnomer occurred it is difficult to determine; some have thought that cotton at that day was only a corruption of coating; at all events the cottons mentioned by the parties alluded to were not made of that material. The first historical notice we meet with is in the *Itinerary of Leland*, who visited Lancashire in the reign of Henry VIII. "Bolton-upon-Moore market," says he, "standeth most by cottons; divers villages in the moores about Bolton do make cottons." From this an inference has been drawn in favour of the existence of the manufacture of cotton in Lancashire at this early period; a supposition which is however completely overturned by an Act passed the 5th and 6th of Edward VI., 1552, entitled, "for the true making of woollen cloth;" in which it is ordered that all the cottons called Manchester, Lancashire, and Cheshire cottons, full wrought to the sale, shall be in length full twenty-two yards, and contain in breadth three-quarters of a yard in the water, and shall weigh thirty pounds in the piece at least. Also, that all other cloths called Manchester rugs, otherwise named Manchester friezes, full wrought for sale, shall contain in length thirty-six yards, and in breadth three-quarters of a yard, coming out of the water, and shall not be stretched on the tenter or otherwise about a nail of a yard in breadth, and, being so fully wrought and well dried, shall weigh every piece forty-eight pounds at the least. However paradoxical it may appear, it is nevertheless clear from this passage of the Act, that the Manchester cottons of that day were a species of woollen cloth, and that of the coarsest and strongest kind, as is sufficiently proved by the weight required by the Statute. The testimony of Camden also to this point is decisive. When speaking of Manchester in 1590, he says, "This town excels the towns immediately around it in handsomeness, populousness, woollen manufactures, market-

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Manufac-
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place, church and college, but did much more excel them in the last age, as well by the glory of its woollen cloths, which they call *Manchester cottons*, as by the privilege of sanctuary which the authority of Parliament under Henry VIII. transferred to Chester."

The manufacture of these cottons was known also in Wales, as appears from the eighth of Elizabeth, 1566; in which we have the following historical fact. "In the town of Shrewsbury there hath been, time out of mind of man, and yet is, a company, fraternity, or guild of the art and mystery of drapers, which said fraternity hath, by reason of a certain trade and occupation of buying and selling of Welsh cloth and linen, commonly called *Welsh cottons*, frizes, and plains, which they have had and used amongst them, been able not only to live thereby, but also have, at their common cost, provided houses and other necessities for poor people within the said town of Shrewsbury." The distinction of the Welsh cottons here into frizes and plains is another proof of their being made of wool.

It is certainly singular, that the term cotton should be applied to goods manufactured wholly of wool, and which from their weight and substance could not possibly be intended as imitations of or substitutes for the cotton goods of any other Country.

The fact is, however, sufficiently evident from the preceding quotations, and still further from the consideration that, at the present day, the Kendal cottons, a manufacture which has subsisted now nearly five centuries, are made entirely of wool, and that of the coarsest kind.

Like the Welsh cottons, they are manufactured both frized and plain, and are used chiefly for negro clothing in America and the West Indies, though some are worn at home by the poor or labouring husbandmen. Various conjectures have been offered respecting the origin of the name, but the most probable is, as we have mentioned, that it is a corruption of the word *coating*. However this may be, it is very certain that the Manchester, Cheshire, and Welsh cottons, which in all probability were derived from those of Kendal, were made entirely of wool, and that it is to these goods the observation of Leland applies in the quotation we have before given.

Early im-
portation of
cotton wool.

It appears, therefore, that we have nothing here on which may be fixed the date of the time at which the cotton manufacture was introduced into England, but cotton in the form of wool had been for centuries imported in small quantities, to be used as candle-wicks, as appears by an entry in the books of Bolton Abbey, Yorkshire, where 27s. 1d. is charged for different articles, and, amongst others, cotton for candles.

The next mention of cotton wool imported, according to Mr. Baines, occurs in *The Processe of the Libel of English Policie*, originally published in 1430, and re-published in Hakluyt's *Collection of Early Voyages*, in which, amongst other imported articles, cotton is included.

At the beginning of the XVIth Century the evidences of a regular importation of cotton become more numerous. Hakluyt records that "in the yeeres of our Lord 1511, 1512, and till 1554, diuers tall ships of London, with certaine other ships of Southampton and Bristow, had an ordinary and vsual trade to Sicilia, Cundie, Chio, and somewhiles to Cyprus, as also to Tripolis Barutti in Syria," and, after stating various articles exported, amongst them is named cottons, (no doubt of the woollen kind already noticed,) and amongst the imported articles cotton wool, which, however,

VOL. VIII.

Mechanical
Processes.

it appears, was used for candle-wicks, probably for beds also, and some few other such purposes. The earliest actual record relating to cotton manufacture is in the year 1641, and there is good reason for concluding that it could not have existed very long before that period, or if it did, it was on too inconsiderable a scale to attract the notice either of the legislature or of any author of note, whose works are still extant. The record above referred to is in a work by Lewis Roberts, called *The Treasure of Traffic*, published in 1641, where he says,

"The town of Manchester, in Lanchashire, must be also herein remembered, and worthily for their encouragement commended, who buy the yarn of the Irish in great quantity, and, weaving it, return the same again into Ireland to sell. Neither doth their industry rest here, for they buy *cotton wool* in London, that comes first from Cyprus and Smyrna, and at home worke the same, and perfect it into *fustians*, *vermillions*, *dimities*, and other stufes, and then return it to London, where the same is vented and sold, and not seldom sent into forrain parts, who have means, at far easier termes, to provide themselves of the said first materials." (Original Edition, p. 32, 33.)

The same author further says, "The Levant or Turkey brings in return thereof (*i. e.* of English woollens) great quantity of *cotton* and *cotton yarn*, grogram yarn, and raw silke into England, (which shows the benefit accruing to this kingdom of that Company;) for here the said cloth is first shipped out and exported in its full perfection, dyed and drest, and thereby the prime native commoditie of this kingdom is increased, improved, and vented, and the cotten yarne and raw silk obtained." (p. 34.)

From the above evidence it is manifest that the cotton manufacture had in 1641 become well established at Manchester. It not only supplied the home trade with several kinds of cotton goods, but furnished them as a regular article of exportation from the metropolis to the distant markets of the Levant; and the importation of cotton wool and cotton yarn had also become regular and considerable. Manchester still retained its manufacture of linen, and as linen yarn was used as the warp for fustians, and nearly all other cotton goods in this Country, down to the year 1773, it may be said that the linen manufacture prepared the way for the cotton manufacture, and long continued its auxiliary. It may therefore from all the above facts be regarded as, in a very high degree, probable, that the cotton manufacture was introduced into England towards the close of the XVIth Century, by the Flemish Protestant Emigrants.

This view receives confirmation from a passage in Fuller's *Worthies of England*. Dr. Fuller, who wrote in 1662, in his notice of Humphery Chetham, the celebrated founder of the Blue Coat Hospital and Library at Manchester, who was born in the year 1580, says, "George, Humphery, and Ralph (Chetham) embarked in the trade for which Manchester had been for some time distinguished, the chief branch of which was the manufacture of cottons. Bolton at that period was no less the market for *fustians*, which were brought thither from all parts of the surrounding country. Of these last, especially, the Chethams were the principal buyers, and the London market was chiefly supplied by them with those materials of apparel *then in almost general use throughout the nation*." Humphery Chetham, "when High Sheriffe of this County, 1635, discharged the place with great honour, inasmuch that very

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Manufac-
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good gentlemen, of birth and estate, did wear this cloth at the assize to testify their unfeigned affection to him; and two of them (John Huntley and W. Wrigley, Esqrs.) of the same profession with himself, have since been sheriffs of the county." (vol. i. p. 554.)

This passage shows that fustians were "in almost general use throughout the nation" while the Chethams were in business; and as Humphery Chetham was High Sheriff in 1635, when he was fifty-five years of age, we may conclude that he had then dealt in that article for a number of years. Of course, fustians must have been made in Manchester and Bolton for a considerable time before the publication of Lewis Roberts' book. The spread of the manufacture was afterwards by no means rapid; the same obstacles which impeded its growth in other Countries of Europe impeded it in England. Owing to the rudeness of the spinning machinery, fine yarn could not be spun, and of course fine goods could not be woven. Fustians, dimities, and other strong fabrics were made, but calicoes and the more delicate cotton goods were not attempted.

From *A Description of the Towns of Manchester and Salford*, attached to a plan of the towns, taken about the year 1650, the following information is derived relative to trade: "The trade is not inferior to that of many cities in the kingdom, chiefly consisting in *woolen, frizes, fustians, sack-cloth, mingled-stuffs, caps, inkles, tapes, points, &c.*, whereby not only the better sort of men are employed, but also the very children, by their own labour, can maintain themselves. There are, besides, all kinds of foreign merchandize brought and returned by the merchants of the town, amounting to the sum of many thousands of pounds weekly." Dr. Fuller, whose authority has been already quoted, and whose work was published in 1662, gives some further information concerning the manufactures of Manchester and Bolton. The passage will not be the less acceptable if we preserve the quaint conceits of the old Divine. After mentioning the names of Jen, Augsburg, and Milan fustians, he says, "These retain their old names at this day, though these several sorts are made in this Country, whose inhabitants, buying the *cotton wool* or *yarne* coming from beyond the sea, make it here into fustians, to the good employment of the poor, and great improvement of the rich therein, serving mean people for their outsides, and their betters for the lining of their garments. Bolton is the *staple place* for this commodity, being brought thither from *all parts of the country*."

"As for *Manchester*, the *cottons* thereof carry away the credit in our nation, and so they did a hundred and fifty years agoe. For when learned Leland, on the cost of King Henry the VIIIth, with his guide, travailed Lanchashire, he called Manchester the fairest and quickest town in this country; and sure I am, it hath lost neither spruceness nor spirits since that time. Other commodities made in Manchester are so small in themselves, and various in their kinds, they *will fill the shop of a haberdasher of small wares*. Being, therefore, too many for me to reckon up or remember, it will be the safest way to wrap them all together in some *Manchester ticken*, and to fasten them with the *pinns*, (to prevent their falling out and scattering,) or tye them with the *tape*, and also because sure bind, sure find, to bind them about the *points* and *laces* all made in the same place."

For the above particulars, quotations, references, &c.

we are indebted to the Work of Mr. Baines, which the reader, who wishes for complete information on this interesting subject, will do well to consult. The facts there stated must have been collected with great labour, and are arranged with judgment and perspicuity, and from them we learn that about the year 1697 the cotton trade had increased so much as to export goods to the amount of £5915, and in 1701 to £23,253 sterling, and that in the same years the weight of cotton imported amounted to 2,000,000 pounds.

Cotton Spinning by Machinery.

(975.) We come now to the second period of the history of the cotton manufactures of Great Britain; viz., to the year 1738, from which we may date the origin of many important inventions in both weaving and carding, as well as the first attempt at roller spinning, which was afterwards so successfully pursued by Arkwright, who is indeed very commonly, but not truly, considered as the original inventor of that process.

Up to the period above stated, no better or more dexterous mode of spinning had been practised than by a wheel and spindle, every single thread requiring the undivided attention of one person, and the consequence was, that a sufficient quantity of the cotton twist could not be obtained to answer the demand of the weaver, even at that time, while the necessarily high price of the article when manufactured prevented much increase in the demand. About this time, the advantage and necessity of a more rapid means of producing the cotton yarn led a highly ingenious person (Mr. John Wyatt, of Birmingham) to turn his attention to the subject, in which, as far as skill and contrivance went, he seems to have possessed every requisite qualification, but he was not, as it would appear, so able a negotiator or merchant as mechanic, and to this, and a want, perhaps, of sufficient support, the manufactory which was established by him in partnership with others failed of the success it so well merited. Our business here, however, is not so much with the success of the undertaking, in a pecuniary point of view, as with the original invention, which in other hands, and in more favourable time, has laid the foundation of many private princely fortunes, and raised Great Britain itself to a mercantile eminence never before attained by any nation of either ancient or modern times.

In every mode of spinning, whether the material be cotton, flax, or wool, the objects to be accomplished are to draw out the loose fibres in a regular and continuous line, and, after reducing them to the requisite continuity, to twist them into threads. Previously to the operation of spinning, the cotton is submitted to a process called carding, which will be described as we proceed. This was formerly effected by hand with single cards; these were afterwards made double, but it was still a work performed by hand, and the cotton was stripped off the cards in loose rolls called *cardings* or *slivers*, and the only difference between the slivers produced by the old hand cards and those by the present carding engine, hereafter to be described, is, that the former were in lengths only of a few inches, while the latter are in lengths of some hundred yards. The sliver thus produced has to be rendered considerably more firm before the cotton can be actually submitted to the process of spinning, and this is now generally effected by two or more small pair of rollers placed horizontally, the upper

Mechanical
Processes.

State of the
cotton ma-
nufacture
in 1738.

Wyatt in-
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the roller
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Manufac-
tures.

and lower roller in each pair revolving in contact. The sliver being put between the first pair of rollers, is by their revolution drawn through and compressed; it is then caught by the second pair of rollers, placed immediately in front, which revolve with three, four, or more times the velocity of the first pair, and which accordingly lengthen the sliver and reduce its sectional area in the same proportion; the sliver in some modern machines is still passed through other pairs of rollers acting precisely on the same principle, and is at length, when properly extended and compressed, attached to a spindle and fly, the rapid revolutions of which twist it into a thread, and at the same time wind it upon a bobbin. In order that these rollers may take a proper hold of the cotton to urge it forward, the lower roller is fluted and the upper one covered with leather.

Such is the beautiful and admirable contrivance by which a machine is made to do what was formerly effected by the fingers only, and of which the honour of the discovery (rather than a minute description) is at present the object of our inquiry. That the process has been gradually and greatly improved since the time when the method was first suggested there is abundant evidence, so also is the steam-engine since Watt's first Patent; but the honour of giving to it its present form is due to that able mechanic, and on precisely the same grounds the honour of spinning by rollers is, we conceive, due to Wyatt, although it was his misfortune to become a bankrupt, while the second inventor, Sir R. Arkwright, made a splendid fortune. The evidence of the first invention being due to a period nearly thirty years prior to Arkwright's is shown by the following verbatim copy of the Patent granted to a foreigner, Lewis Paul, for this invention, and which is only witnessed by the actual inventor Wyatt; but other manuscript documents which have been inspected by Mr. Baines, and of which he has given extracts, leave no doubt that, whatever might have been the motive for taking out the Patent in the name of Lewis Paul, John Wyatt was the author of the invention.

(976.) Patent for Spinning by Rollers in 1738.

"Twentieth part of Close Rolls in the Twelfth Year of King George the Second.

Lewis
Paul's first
Patent, the
invention
of Wyatt.

"Lewis Paul's description } TO ALL TO WHOM THESE PRESENTS shall come, Lewis Paul, of Birmingham, in the county of Warwick, gentleman, sendeth greeting. Whereas his present Majesty, by his Royall Letters Patent, under the seal of Great Britain, bearing date the twenty-fourth day of June, in the twelfth year of his reign, hath given and granted unto me, the said Lewis Paul, my executors, administrators, and assigns, sole privilege and authority to make, use, exercise, and vend a new invented machine or engine, for the spinning of wooll and cotton, in a manner entirely new; To have, hold, exercise, and enjoy the said licence, unto me, my executors, administrators, and assigns, for the term of fourteen years, from the date of the said Letters Patent, according to the statute in such case made and provided. In which said Letters Patent is contained a provisal, that if I, the said Lewis Paul, shall not particularly describe and ascertain the nature and form of the said invention, and in what manner the same is to be performed, by an instrument in writing under my hand and seal, and cause the same

to be inrolled in the High Court of Chancery within two calendar months after the date of the said Patent, the same was to be void, as by the said Letters Patent, relation being thereon to be had, may appear. Now know all men by these presents, that I, the said Lewis Paul, do by this present writing, under my hand and seal, declare the nature and form of the said invention to be, and the manner the same is to be performed by, is as follows, to wit. The said machine, engine, or invention will spin wooll or cotton into thread, yarn, or worsted, which, before it is placed therein, must be first prepared in manner following: (to wit:) all those sorts of wooll or cotton, which it is necessary to card, must have each card-full batt, or roll, joined together so as to make the mass become a kind of rope, or thread, of raw wooll. In that sort of wooll which it is necessary to combe, commonly called jarsey, a strict regard must be had to make the slivers of an equal thickness from end to end. The wooll or cotton being thus prepared, one end of the mass, rope, thread, or sliver, is put betwixt a pair of rowlers, cillinders, or cones, or some such movements, which, being twined round by their motion, draws in the raw mass of wooll or cotton to be spun, in proportion to the velocity given to such rowlers, cillinders, or cones; as the prepared mass passes regularly through or betwixt these rowlers, cillinders, or cones, a succession of other rowlers, cillinders, or cones moving proportionary faster than the first, draw the rope, thread, or sliver into any degree of fineness which may be required: sometimes these successive rowlers, cillinders, or cones (but not the first) have another rotation besides that which diminishes the thread, yarn, or worsted, (viz.) that they give it a small degree of twist betwixt each pair, by means of the thread itself passing through the axis and center of that rotation. In some other cases only the first pair of rowlers, cillinders, or cones are used, and then the bobbyn, spole, or quill upon which the thread, yarn, or worsted is spun, is so contrived as to draw faster than the first rowlers, cillinders, or cones give, and in such proportion as the first mass, rope, or sliver is proposed to be diminished. In witness whereof I have hereunto set my hand and seal, the twentieth day of July, in the year of our Lord One Thousand Seven Hundred and Thirty-Eight.

LEWIS PAUL.

"Signed and sealed (being first duly stamped) in the presence of us,

SAMUEL GUY,
JOHN WYATT.

"And be it remembered, that the twentieth day of July, in the year above written, the aforesaid Lewis Paul came before our said Lord the King in his Chancery, and acknowledged the description aforesaid, and all and every thing therein contained and specified, in forme above written, and also the description aforesaid was stampd according to the tenor of the statute made in the sixth year of the reign of the late King and Queen, William and Mary of England and so forth. Inrolled the twentieth day of July, in the year above written.

THOMAS BENNETT.

"This is a true copy from the original record remaining in the Chapel of the Rolls, having been examined.

JOHN KIPLING."

Mechanical
Processes.

Manufac-
tures.
Roller spin-
ning at Bir-
mingham
and North-
ampton.

This important document, although placed amongst the other recorded Patents at the Patent Office, has been only very recently made public in Mr. Baines's Work already referred to: he was furnished with it by Mr. Guest, another able author on the cotton manufactures, but who had not fallen upon it when his last edition was printed. It was known that some such Patent existed, but it having always been sought for in Wyatt's name, the search had hitherto been unsuccessful.

There can, we think, be no longer any doubt concerning the author of this highly ingenious and important invention, and other manuscript documents prove that not only was the Patent then granted, but also that the manufacture of cotton yarn, founded on this process, was carried on at Birmingham in 1741—2, and another at Northampton; there is also proof by a letter from Mr. Wyatt, addressed to Sir Leicester Holt, that he had shared the fate of numerous other ingenious inventors, the letter being from him while a prisoner for debt, requesting Sir Leicester to support a Bill then before Parliament for the relief of insolvents.

The following narrative by Mr. Charles Wyatt, relative to his father's claims, as above stated, will, we trust, be found highly interesting; it is addressed to his brother, then editor and publisher of the *Repertory of Arts*, and is published in the Number of January, 1818. We give it verbatim.

"Bedford-row, Nov. 15, 1817.

Particulars
of Wyatt's
claim by his
son.

(977.) "Dear Brother,—In compliance with your request, I send you some account of the origin of the present method of spinning by machinery, for insertion in the *Repertory of Arts and Manufactures*, which being a receptacle of useful knowledge, nothing can with more propriety fill up a part of its columns. Our chief view, however, in this is to rescue from oblivion, and affix the gratitude of a nation upon a name dear to us and unknown to those who are exalted, though perhaps unconsciously, by his genius—our parent John Wyatt, of Birmingham.

"To produce something out of nothing is a greater effort of excogitation than to improve what is already produced. The production then of a system of machinery to supersede the artless method of spinning with the fingers, may be justly classed among the highest efforts of mechanical combinations, and this was accomplished early in the last Century by the individual here spoken of. The brief history of the invention, for the narration of which my superior years, and the circumstance of being in possession of his papers and memorandums on the subject, give me an advantage over you, as far as I am able to trace it, is this. In the year 1730, or thereabouts, living then at a village near Lichfield, our respected father first conceived the project and prepared to carry it into effect; and in the year 1733, by a model of about two feet square, in a small building near Sutton Coldfield, without a single witness to the performance, was spun the first thread of cotton ever produced without the intervention of the human fingers, he, the inventor, to use his own words, '*being all the time in a pleasing but trembling suspense.*' The wool had been carded in the common way, and was passed between two cylinders, from whence the bobbins drew it, by means of the twist. This successful experiment induced him to seek for a pecuniary connection equal to the views that the project excited; and one appeared to present itself with Mr. Lewis Paul, which terminated unhappily for the pro-

jector; for Paul, a foreigner, poor and enterprising, made offers and bargains which he never fulfilled, and contrived in the year 1738 to have a Patent taken out in his own name for some additional apparatus, a copy of which I send; and in 1741 or 1742, a mill, turned by two asses walking round an axis, was erected in Birmingham, and ten girls were employed in attending the work. Two hanks of the cotton then and there spun are now in my possession, accompanied with the inventor's own testimony of the performance. Drawings of the machinery were sent to Mr. Cave, for insertion in the *Gentleman's Magazine*.

"This establishment, unsupported by sufficient property, languished a short time and then expired; the supplies were exhausted, but his confidence in the scheme was unimpaired. The machinery was sold in 1743. A work upon a larger scale, on a stream of water, was established at Northampton, under the direction of a Mr. Yeoman, but with the property of Mr. Cave. The work contained 250 spindles, and employed fifty pair of hands. The inventor soon after examined the state of the undertaking, and found great deficiency and neglect in the management. At that time they had spun about 3300 pounds of cotton. On the observations which he then made, he composed what he entitled *A Systematic Essay on the Business of Spinning*, which exhibits a clear view of the mechanical considerations on which an undertaking of that nature, of whatever magnitude, must be established, and apparently confines his humble pretensions to the profit on 300 spindles. It was not within human foresight to calculate the richness of the harvest to come from this little green germ.

"This brings me to the conclusion of our father's connection with the spinning business. The work at Northampton did not prosper; it passed, I believe, into the possession of a Mr. Yeo, a gentleman of the law, in London, about the year 1764; and from a strong coincidence of circumstances there is the highest probability that the machinery got into the hands of a person who, with the assistance of others, knowing how to apply what might be deficient, raised upon it, by a gradual accession of profit, an immense establishment and a princely fortune.

"In the year 1739 my father writes to one of his best friends, '*that by this method,*' some new thought, '*the wool need to be no more carded than to break the knots or mix it well as with scribbles or stock cards, and being thus mixed and pressed down hard into a box, it may, without any human touch, be picked out almost hair by hair and made into yarn.*'

"In 1748 Mr. Paul procured another patent, the title of which was '*for carding of wool and cotton;*' but whether this was combined with the machinery then at Northampton, or where it was introduced, I know not. Such, or nearly such, being the early history of this invention, I thought the late Sir Richard Arkwright would be gratified by possessing the very model to which I have alluded, and I accordingly waited on him at Cromford with the offer, but my reception did not correspond with my expectations.

"To pretend, however, that the original machinery, without addition or improvement, would alone have produced the prodigious effects which we now behold, would be claiming improbable merit for the inventor, and degrading the talents and sagacity of his successors in the same field of enterprise; for it cannot be denied that a great fund of ingenuity must have been expended

Mechanical
Processes.

Manufac-
tures.

in bringing the spinning works to their present degree of perfection. The number of spindles now in use is supposed to exceed 5,000,000.

"If the author of the humble establishment at Birmingham gave birth to such a wonderful progeny, he ought at least to be acknowledged as a benefactor to his Country, and recorded among the men who, from an attachment to the sciences and practice of mechanics, open the path of knowledge and point out, but do not pursue, those which lead to profit and prosperity. Connected with this subject, I might, with great propriety, point out many eminent services that he rendered the public by his mechanical talents; but being mostly local, and absorbed by subsequent productions, they have lost their present interest. The machine, however, for weighing loaded carriages, coal particularly, ought to be distinguished as one of known and extensive utility. It was solely and exclusively his own; he erected the first in Birmingham about fifty years ago, and his own description of it is, *that it would weigh a load of coal or a pound of butter with equal accuracy*. The present makers admit that the principle is incapable of improvement.

"The late Mr. Boulton, a man too eminent and too amiable to be mentioned without esteem and regret, nor on my part without affection, set a high value both on my father's attainments and virtues; for it was universally acknowledged that he had the happiness to give a lustre and an interest to his genius and his knowledge by the purest probity, the most unaffected humility, urbanity, and benevolence. He was attended to his grave, in 1766, by Mr. Boulton, Mr. Baskerville, the celebrated printer, (who, from the peculiarity of his notions, arrayed himself on this occasion in a splendid suit of gold lace,) and four other gentlemen of eminence in Birmingham.

"I am, dear brother, affectionately,
"CHARLES WYATT."

Remarks
on Wyatt's
machines.

(978.) We have thought it right to enter at the length we have done into the claims of Mr. Wyatt; the invention was undoubtedly unsuccessful in his hands, and the machine, in all probability, wanted alterations and improvements which either did not occur to him, or, if they did, were such as his pecuniary means would not allow him to adopt, and it would be as unjust to deny to Arkwright all the merit of rendering perfect what was in its first form defective, as it would be to deny to Mr. Wyatt the honour of the original invention. We have seen that the first Patent is dated 1738; that cotton yarn was spun by means of it in 1741, 1742, and 1743, when the whole seems to have been dropped; it was again revived, or a new Patent taken out, by Paul in 1758, and in 1767 a person of the name of Highe is said to have employed himself in constructing another machine on similar principles; that he employed a clock-maker of the name of Kay to assist him in the brass work; that Kay was afterwards employed by Arkwright, and that the latter thus became acquainted with Highe's invention and availed himself of that knowledge in constructing and completing that machine which was to him, and has been since to many, the source of great riches, and is of such a high and important advantage to the nation at large.

Highe and
Kay's
claims.

We have not the room, neither do there appear to be the materials, necessary for deciding these claims of Highe and Kay; they rest principally upon the testimony of these two persons on a trial, in which Arkwright's Patent was disputed, in 1785. We shall only observe,

that after the Patents of 1738 and 1758, there can be no doubt that by persons interested in such constructions the principles adopted in the Patents would be studied, and important alterations introduced; that such might be the case with Highe; that through Kay, Arkwright might be made acquainted with some additional step taken by Highe, and to these adding certain combinations of his own, as others have still done to his, a machine has been produced which for ingenuity and importance has never been equalled in any Age or nation.

(979.) Arkwright's Patent was enrolled in 1767, under the denomination of the Water Frame, simply from the circumstance of the first machines having been worked by means of a water wheel. We have already referred to the names of two persons, Highe and Kay, and their claims on the invention of Arkwright. There is in fact no doubt, we believe, that Kay was first employed by Highe to make a model of a roller spinning machine, that this Kay was afterwards employed by Arkwright, and that subsequently the latter took out his Patent. Arkwright was not in any way originally connected with the cotton trade, having been born in humble circumstances and apprenticed to a barber at Preston; and only accidentally, as it would appear, fell in with Kay, who was a watch-maker at Warrington, and whom he engaged to assist him in the construction of his first engine, which, there seems every reason to believe, differed very essentially from any other which had hitherto been constructed, but the exact degree of difference it is of course impossible now to decide, although we have a very explicit description of his own machine in the specification of his Patent, with explanatory drawings, which is not the case in Wyatt's original Patent, and as for Highe's machine it is doubtful whether it was ever completed. It would, however, be inconsistent with a concise sketch of this kind, to enter into a minute description of this early form of the roller spinning machine, which is no more like the same machine of the present day than that machine itself was like any of those which had preceded it. We shall reserve, therefore, what we shall have further to add to the subject till we have to describe the modern process of cotton manufacture.

Mechanical
Processes.

Arkwright's
water
frame.

(980.) *Invention of the spinning jenny.*—About two years, or more probably four years, prior to Arkwright's Patent, a machine, altogether of a different description, was invented by a poor man of the name of Hargreaves, and called by him a spinning jenny. Hargreaves was a weaver at Stanhill, near Church, a few miles distant from Blackburn, in Lancashire; he was a plain, industrious, but illiterate man, and possessed little operative mechanical skill. His residence was near the print ground, the first and infant establishment of the late Sir Robert Peel, from whose hints and conversation he derived much important assistance, and whose strong and active mind was at that time engaged in the promotion of every useful improvement connected with that branch of manufacture in which he was afterwards so extensively connected. An anecdote is still recorded in the neighbourhood which ascribes to accident, the parent of so many useful discoveries, the first invention of the jenny. A number of young people were one day assembled at play in Hargreaves' house during the hour generally allotted to dinner, and the wheel at which he, or some one of his family, was spinning was by accident overturned; the thread still remained in the hand of the spinner, and as the arms and periphery of the wheel were prevented by the framing from any contact with

Invention
of the spin-
ning jenny

Manufac-
tures.

the floor, the velocity it had acquired still gave motion to the spindle, which continued to revolve as before; Hargreaves surveyed this with mingled curiosity and attention, he expressed his surprise in exclamations, which are still remembered, and continued again and again to turn round the wheel as it lay on the floor, with an interest which was at that time mistaken for indolence: he had before attempted to spin with two or three spindles affixed to ordinary wheels, holding the several threads between the fingers of his left hand, but the horizontal position of the spindles rendered this attempt ineffectual; it is not therefore improbable that he derived from the circumstance above mentioned the first idea of that machine, which paved the way for subsequent improvement. It consisted at first of only eight spindles turned by bands from a horizontal wheel, in the centre of which was fixed a vertical shaft, with a handle at the top for the spinner. The thread passed between two horizontal pieces of wood the breadth of the machine, which, when pressed together, clasped fast the roving like the finger and thumb of the spinner, and were thus extended or drawn out. He had great difficulty in putting up the thread or winding it on the spindle after twisting, which he at last accomplished by means of a treadle connected with a wire, and worked by the foot of the spinner. The jenny, in its original form, was a rude machine; the first was made almost wholly with a pocket-knife, and the clasp by which the thread was drawn out was the stalk of a briar split in two: it was, as may readily be conceived, defective in the construction of those parts essential to the performance of its work, and which an ordinary mechanic would have had no difficulty in contriving; but Hargreaves was obliged to work in secret, and possessing little mechanical skill, to avail himself of such assistance as he could procure without making public the object he had in view.

Popular prejudice was soon excited against him, and the threats of his neighbours obliged him to conceal his machine for some time after it supplied the woof or weft for his own looms. It was, however, generally known that he had made a spinning machine, and his wife, or some of his family, having imprudently boasted of having spun a pound of cotton during a short absence from the sick bed of a neighbouring friend, the minds of the ignorant and misguided multitude became alarmed, and they shortly after broke into his house, destroyed his machine, and also part of his furniture. Hargreaves soon after removed to Nottingham, whither he was invited by the stocking weavers of that place, and where he assisted in the erection and management of a mill, about the time that Mr. Arkwright first settled there, after being in the same manner driven out, or rather deterred from settling in Lancashire, by the clamour and prejudice of the people. Hargreaves was little qualified, either by education or address, for the sphere of life into which he was removed, and after having assisted various persons in the construction of machinery and communicated to each by turns the whole of what he knew, he died but little enriched by his important discovery. Before he quitted Lancashire he had made one or two wheels of twelve or sixteen spindles, each for some of his relations or friends, and as the popular clamour abated, the number of these increased, till a second mob scoured the whole country and destroyed every machine they could meet with; the value of this improvement, however, was so strongly felt, and the measures adopted against the ringleaders of this outrage were so vigorous

and decisive, that new wheels were immediately constructed, and it was remarked that many of those concerned in opposing their first introduction were amongst the foremost to avail themselves of the advantages they now promised. Various alterations were made in the original machine, which, from its form, was inconvenient and tiresome to grown up persons, though girls of twelve or fourteen managed it with ease. The vertical wheel was substituted for the horizontal one, which rendered it much easier to work; and the treadle, which required an awkward and constrained posture, was rendered unnecessary by a simple contrivance managed by the hand. They were enlarged in their dimensions from twelve to twenty, and afterwards to thirty, fifty, and even eighty spindles, and their use rapidly extended over all the country, though their first introduction every where met with the most determined opposition; even at Nottingham, if our information be correct, a serious affray took place on the first erection of the new machines, in which Hargreaves himself was severely wounded, and a young woman who had accompanied him from Lancashire, and had been accustomed to the management of the first jenny, nearly lost her life.

It has been generally supposed that Hargreaves, at last, died in the parish workhouse, or at least in a state of great poverty; it is satisfactory, however, that we are enabled, on the authority we have frequently quoted, Mr. Baines, to contradict this statement; he gives the following account of the last days of this highly distinguished mechanic. Hargreaves had a partner, Mr. James; and from a son of that gentleman, and from a grandson of Hargreaves, as well as from others, it appears that James Hargreaves went to Nottingham in 1768, and that while in the employment of Mr. Shipley, for whom he made some jennies secretly in his own house, he was induced by the offers of Mr. Thomas James to enter into partnership with him; and that the latter raised sufficient money, on mortgage and loan, to build a small mill at Hockley, where they spun yarn for the hosiers with the jenny. The Patent was obtained in 1770. Finding that several of the Lancashire manufacturers were using the jenny, Hargreaves gave notice of actions against them; the manufacturers met and sent a delegate to Nottingham, who offered Hargreaves £3000 for permission to use the machine; he at first demanded £7000, but at last dropped his demand to £4000, which was, however, resisted. The negotiations being broken off, the actions proceeded, but before they came to trial Hargreaves' attorney, learning that his client, before leaving Lancashire, had sold some jennies, which of course barred his action, gave up the business in despair of obtaining a verdict. The spinning business was carried on by the partners with moderate success, till the death of Mr. Hargreaves, which took place at his own house near the mill in April, 1778. In his will he directed a guinea to be given to the vicar for preaching his funeral sermon, and his widow received £400 from Mr. James for her husband's share of the business, and having other property which her husband had accumulated she left this sum to his children at her death. The reports of his abject poverty are, therefore, erroneous, for although it is certain he did not derive, from his ingenuity, all the pecuniary advantages he so well merited, he, at all events, ended his days in comparatively comfortable circumstances.

(981.) *Invention of the carding machine.*—In order to connect together the two great inventions in cotton spin-

Mechanical
Processes.

Carding.

Manufac-
tures.

Paul's
Patent.

ning we have hitherto said little on a prior process, that of carding; to which the cotton is subjected after it has been opened and cleaned in order that the fibres of the wool may be disentangled, straightened, and laid parallel with each other so as to admit of being spun. It has been already stated that this was formerly effected by hand cards made like flat brushes, but made of short wires instead of bristles, the wires having been stuck through a piece of leather at a certain angle, and the leather then laid on its back on a piece of flat board. These hand cards received some improvements, but the first great step towards the present machine was made by Lewis Paul in 1748. This Patent includes two different machines for the same purpose, the one a plane and the other a cylindrical arrangement of cards. The card is made up of a number of parallel cards with intervening spaces between each, and the material being carded thereon is afterwards taken off each separately, and the several rows or filaments of wool or cotton so taken off are connected into one entire roll.

The first machine consisted of a flat board varying in dimensions from three feet by two feet to two feet by fourteen inches, on which were nailed sixteen long cards parallel to each other, with small spaces between each two; but the second, which may be considered as the model of the present carding engine, was a horizontal cylinder, covered in its whole circumference with intervening spaces. Under the cylinder was a concave frame lined internally with cards exactly fitting the lower half of the cylinder, so that when the cylinder was turned, the cards of the concave frame worked against those on the cylinder and carded the cotton or other material passed between them. When the wool was sufficiently carded it was stripped off by means of a stick with needles in it parallel to one another like the teeth of a comb. The cardings were of course only the length of the cylinder, but an ingenious apparatus was attached for making them into a perpetual carding. Each piece was placed on a flat broad riband which was extended between two short cylinders, and which wound upon one cylinder as it unwound from the other. When the carding was placed on the riband, the turning of one of the cylinders wound the riband and carding upon it, and being joined length to length the carding or sliver was made perpetual, and was wound up in a roll ready for the spinning machine.

This apparatus, which is undoubtedly in its principle of operation the same as the modern carding engine, was turned only by hand, and was in other respects defective, yet it displayed the talents of its inventor to advantage, although it does not appear that he benefited much by it in a pecuniary point of view. Its defects were that the cylinder had no feeder, the wool having to be put on by hand; that the cardings were taken off separately by a movable comb, which required the machine to be stopped; and the perpetual carding was produced only by joining together short lengths by hand; lastly it was turned by hand, and of course with great labour. We shall see, as we proceed, how admirably all these objects are accomplished in combination with the spinning process almost without manual labour or mental attention.

(1782.) *Invention of the mule.*—There still remained an important step to be made in the art of cotton spinning, for which the nation is indebted to Mr. Samuel Crompton. This is called the mule, or mule jenny, from its combining the principles of the roller spinning of

Arkwright with the spinning jenny of Hargreaves; like the former it has a system of rollers, and like the latter it has spindles without bobbins to give the twist, and the thread is stretched and spun at the same time by the spindles after the rollers have ceased to give out the rove. The great difference between this and the two former machines is, that instead of the spindles being stationary they are placed on a movable carriage, which is wheeled out to distances of from four to five feet from the roller beam, in order to stretch and twist the thread, and then wheeled in again to wind it up on the spindles. This important improvement, as we have stated, was made by Samuel Crompton, a weaver of respectable character and moderate circumstances, living at Hall-in-the-Wood, near Bolton, about the year 1775, or rather perhaps between the years 1774 and 1779, for it does not appear that he had rendered it perfect before the latter year, although he had conceived the idea of it, and commenced working upon it in 1774. Crompton was of a retiring and unambitious disposition, he therefore sought no aid and took out no Patent, and only regretted that public curiosity would not allow him to enjoy his invention as his own, and to earn by his manual labour undisturbed the fruits of his ingenuity and perseverance; from which indeed he might have reaped considerable advantages, as the great perfection of his yarn ensured to him plenty of customers and high prices. Cotton yarn is designated by different numbers, as No. 40, No. 60, No. 80, &c., implying that there are so many hanks to the pound, the length of each hank being always 840 yards. For No. 40 he obtained fourteen shillings per pound; for No. 60, twenty-five shillings; and for No. 80, forty-two shillings, the latter No. having been thought (till he produced it so fine) an actual impossibility; but such has since been the extent of improvement that No. 100 is now sold for three shillings per pound, and while a few years back No. 80 was considered as a wonder, there has been produced No. 350, that is, three hundred and fifty hanks, each eight hundred and forty yards long, have been spun, weighing only one pound.

As in the cases of the roller spinning engine and the spinning jenny, the mule was in its first form very imperfect compared with what it is at present: it at first consisted of not more than twenty or thirty spindles; in a subsequent stage the number of spindles were increased to 100 and 130, then came the double mule with a greater number, and at the present day there are mules working in Manchester and other places in which the number of spindles vary from 800 to 1100, and the double mules to the prodigious number of 2200. Notwithstanding the extraordinary importance of this invention, the machine not being secured by a Patent, the inventor rose but little out of the sphere of life he was in originally, till in 1812 the value of the apparatus was represented to Parliament, by whom was granted to him a reward of £5000; with this sum it appears he set his sons up in the cotton printing trade, but through misfortune and mismanagement it was all sunk, and the inventor at length was left to subsist upon a pension or annuity raised for him by private subscription, amounting to £63 per annum, and for which he was much indebted to the kind consideration and active benevolence of Mr. Kennedy, who afterwards published a brief memoir of him.

We must here conclude our historical sketch of the improvements in cotton spinning, not for want of materials, but for want of space; for every year during the

Mechanical
Processes.

Invention
of mule
spinning.

Manufac-
tures.

present century has been adding improvements upon improvements: we must therefore be content with simply mentioning the names of a few of the many contributors towards the perfection to which this operation is now arrived; of these we may enumerate Messrs. Eaton, of Wilne in Derbyshire; Mr. Dyer and Mr. Peter Ewart, of Manchester; Mr. De Jongh, of Warrington; Mr. Buchanan, of Catrine Works; Mr. Knowles and Mr. Roberts, of Manchester; Mr. Kelly, of Lanark; to whom we might add many others having like claims to honourable distinction.

Summary
of the
several
inventions.

We have already repeatedly acknowledged our obligations for many of the facts contained in the preceding sketch to the *History of the Cotton Manufacture*, by Edward Baines, jun. Esq.; we are also under obligation to Mr. Guest, and for some facts to the *Encyclopædia Britannica*; we beg also to add one other abstract from the Author first named, with which he concludes his interesting history of cotton spinning.

"Having thus," he observes, "traced the spinning machinery up to the present time, let us pause to cast a retrospective glance on the different stages by which the process of spinning has advanced from the time when the one-thread wheel was in general use. Little more than sixty years since every thread used in the manufacture of cotton, wool, worsted, and flax throughout the world was spun singly by the fingers of the spinner with the aid of that *classical* instrument, the domestic spinning wheel. In 1764 an *eight-handed* spinster sprung from the genius of Hargreaves, and the *jenny*, with still increasing powers, made its way into common use in spite of all opposition. Two years afterwards the more wonderful invention of Wyatt, which claims a much earlier origin, but which had disappeared like a river that sinks into a subterraneous channel and now rose again under the fortunate star of Arkwright, claimed yet higher admiration, as founded on principles of more extensive application. Five years later, the happy thought of combining the principles of those two inventions to produce a third much more efficient than either, struck the mind of Crompton, who, by a perfectly original contrivance, effected the union. From twenty spindles this machine was brought, by more finished mechanism, to admit of a hundred spindles, and thus to exercise a *Briarean* power. Kelly relinquished the toilsome method of turning the machine by hand, and yoked to it the strength of the rapid Clyde. Watt, with the subtler and more potent agency of steam, moved an iron arm that never slackened or tired, which whirls round two thousand spindles in a single machine. Finally, to consummate the wonder, Roberts dismissed the spinner and leaves the machine to its own infallible guidance. So that in the year 1834 several thousand spindles may be seen in a single room revolving with inconceivable rapidity, with no hand to urge their progress or to guide their operations; drawing out, twisting, and winding up as many thousand threads with unfailing precision, indefatigable patience and strength; a scene as magical to the eye which is not familiarized with it, as the effects have been marvellous in augmenting the wealth and population.

"If the thought should cross any mind that, after all, the so much vaunted genius of our mechanics has been expended in the insignificant object of enabling men better to pick out, arrange, and twist together the fibres of a vegetable wool; that it is for the performance of this minute operation that so many energies have been

exhausted, so much capital employed, such stupendous structures raised, and so vast a population trained up; we reply, our object is not insignificant because the operation by which it is effected is *minute*; the first want of men in this life, after food, is *clothing*, and as *this* art enables them to supply it far more easily and cheaply than the old methods of manufacturing, and to bring cloths of great elegance and durability within the use of the humble classes, it is an art whose utility is inferior only to that of agriculture. It contributes directly and most materially to the comforts of life among all nations where manufactures exist, or to which the products of manufacturing industry are conveyed; it administers to the comfort and decency of the poor, as well as to the taste and luxury of the rich. By supplying one of the great wants of life with a much less expenditure of labour than was formerly needed, it sets at liberty a larger proportion of the population to cultivate literature, science, and the fine arts. To this country the new inventions have brought a material accession of wealth and power. When it is also remembered that the inventions, whose origin I have endeavoured carefully to trace, are not confined in their application to one manufacture, however extensive, but that they have given nearly the same facilities to the woollen, the worsted, the linen, the stocking, and the lace manufactures as to the cotton; and that they have spread from England to the whole of Europe, to America, and to parts of Africa and Asia; it must be admitted that the mechanical improvements in the art of spinning have an importance which it is difficult to over estimate. By the Greeks, their authors would have been thought worthy of deification; nor will the enlightened judgment of moderns deny that the men to whom we owe such inventions deserve to rank among the chief benefactors of mankind.

"The dissolution of Arkwright's Patent, and the invention of the mule, concurred to give the most extraordinary impetus to the cotton manufacture. Nothing like it has been known in any other great branch of industry. Capital and labour rushed to this manufacture in a torrent, attracted by the unequalled profits which it yielded. Numerous mills were erected and filled with water frames, and jennies and mules were made and set to work with almost incredible rapidity. The increase of weavers kept pace with the increase of spinners; and all classes of workmen in this trade received extravagantly high wages; such as were necessary to draw from other trades the amount of labour for which the cotton trade offered profitable employment, but such as it was impossible to maintain for any lengthened period."

(983.) In concluding our sketch of this division of the cotton manufactures of Great Britain, it will be interesting to the reader to see the increase of importation of cotton-wool, and in the export of cotton twist, during the latter and the present century.

Return of Cotton Wool imported into Great Britain at several intermediate Years between 1701 and 1800.

Years.	Pounds.
1701	1,985,868
1701 }	
1705 }	average 1,170,881
1710	ditto 715,008
1720	ditto 1,972,805
1730	ditto 1,545,472

Mechanical
Processes.

Manufac-
tures.

Years.	Pounds.
1741 average	1,645,031
1751 ditto	2,976,610
1764 ditto	3,870,392
1771 } ditto	4,764,589
1776 } ditto	6,766,613
1780 } ditto	5,198,778
1781	11,828,039
1782	

Years.	Pounds.
1783	9,735,663
1784	11,482,083
1785	18,400,384
1786	19,475,020
1787	23,250,268
1788	20,467,436
1789	32,576,023
1790	31,447,605
1800	56,010,732

Mechanical
Processes.

TABLE showing the Quantity Imported, and the Country from which the Importation has been made, between the Years 1820 and 1831.

IMPORTED FROM FOREIGN COUNTRIES.							
Years.	United States of America.	Brazil.	Turkey and Egypt.	Other Foreign Countries.	Total from Foreign Countries.	Rates of Duty.	Gross Amount of Duty received on Quantities entered for Home Consumption.
	lbs.	lbs.	lbs.	lbs.	lbs.	Per Cent. ad valorem.	£. s. d.
1820	89,999,174	29,198,155	285,350	2,045,147	121,527,826	£6.	359,294 1 8
1821	93,470,745	19,535,786	856,868	2,504,180	116,367,579	"	258,745 8 7
1822	101,031,766	24,705,206	395,077	1,534,483	127,666,532	"	241,223 10 11
1823	142,532,112	23,514,641	1,334,547	1,988,773	169,370,073	"	308,185 17 5
1824	92,187,662	24,849,552	7,719,368	1,278,720	126,035,302	"	236,160 3 1
1825	139,908,699	33,180,491	18,938,246	7,245,229	199,272,665	"	498,778 2 3
1826	130,858,203	9,871,092	10,032,400	755,153	151,516,848	"	218,891 5 6
1827	216,924,812	20,716,162	5,071,579	1,279,873	243,992,426	"	319,962 19 10
1828	151,752,289	29,143,279	6,926,288	1,579,711	189,401,567	"	273,774 13 10
1829	157,187,396	28,878,386	5,986,385	1,070,800	193,122,967	"	236,103 0 3
1830	210,885,358	33,092,072	3,401,710	639,823	248,018,963	"	357,455 15 1
1831	219,333,628	31,695,761	8,081,024	697,691	259,808,104	5s. 10d. per cwt.	363,192 18 3
IMPORTED FROM BRITISH POSSESSIONS.							
Years.	East Indies and Mauritius.	British West Indies.		Other British Possessions.	Total from British Possessions.	Rates of Duty charged.	Gross Amount of Duty received on Quantities entered for Home Consumption.
	lbs.	The growth of.	Foreign.	lbs.	lbs.		£. s. d.
1820	23,125,825	6,219,625	617,191	182,188	30,144,829	On East India cotton £6 per cent. ad valorem to 10th Aug. 1828, then 4d. per cwt.	73,865 11 8
1821	8,827,107	5,854,944	1,284,036	202,954	16,169,041	On West India cotton 6s. 3d. per 106 lbs. to 11th March, 1821; then free to 10th Aug. 1828, and then 4d. per cwt.	37,063 19 10
1822	4,554,225	9,031,904	1,263,210	321,757	15,171,096	Of the produce of other British possessions £6 per cent. ad valorem, to 10th Aug. 1828; and then 4d. per cwt.	24,017 13 10
1823	14,839,117	5,719,610	1,315,183	158,520	22,032,430	From 23d Aug. 1831, 4d. per cwt.	21,292 11 9
1824	16,420,005	5,006,002	1,263,304	655,509	23,344,820		19,642 8 11
1825	20,294,262	7,413,764	780,184	244,416	28,732,626		31,054 18 10
1826	21,187,900	4,510,302	240,768	151,583	26,090,553		10,494 19 10
1827	20,984,916	6,227,172	938,709	305,686	28,456,483		12,893 9 1
1828	32,247,187	5,893,800		218,088	38,359,075		8,023 15 0
1829	24,908,399	4,640,414		95,631	29,644,444		2,719 16 1
1830	12,483,217	3,429,247		30,025	15,942,489		3,181 11 0
1831	25,805,153	2,228,927	172,758	659,911	28,866,749		4,948 12 8

Manufac-
tures.

TOTALS.

Mechanical
Processes.

Years.	Total Quantity Imported.	Total Quantity Exported.	Total Quantity entered for Consumption.	Total Gross Amount of Duty received.			Total Net Amount of Duty received.		
	lbs.	lbs.	lbs.	£.	s.	d.	£.	s.	d.
1820	151,672,655	6,024,038	152,829,633	431,159	13	4	426,957	11	3
1821	132,536,620	14,589,497	137,401,549	295,809	8	5	287,349	15	1
1822	142,837,628	18,269,776	143,428,127	265,241	4	9	258,614	11	1
1823	191,402,503	9,318,402	186,311,070	329,478	9	2	327,700	19	6
1824	149,380,122	13,299,505	141,038,743	255,802	12	0	255,258	6	9
1825	228,005,291	18,004,953	202,546,869	529,833	1	1	526,651	5	0
1826	177,607,401	24,474,920	162,889,012	229,386	5	4	228,916	18	10
1827	272,448,909	18,134,170	249,804,396	332,856	8	11	332,355	11	11
1828	227,760,642	17,396,776	208,987,744	281,798	8	10	281,178	8	7
1829	222,767,411	30,289,115	204,097,037	238,822	16	4	238,378	9	4
1830	263,961,452	8,534,976	269,616,640	360,637	6	1	359,988	0	5
1831	288,674,853	22,308,555	273,249,653	368,141	10	11	363,538	14	8

Quantity of Cotton Twist Exported from Great Britain between the Years 1820 and 1831.

Years.	Weight.	Yarn.	Declared Value.
1820	23,032,325	2,826,639	16,516,748
1821	21,526,369	2,305,823	16,093,787
1822	26,595,468	2,697,582	17,218,724
1823	27,378,986	2,625,946	16,326,604
1824	33,605,510	3,135,396	18,452,987
1825	32,641,604	3,206,729	18,359,526
1826	42,189,661	3,491,338	14,093,369
1827	44,878,774	3,545,578	17,638,165
1828	50,505,751	3,595,405	17,244,417
1829	61,441,251	3,976,874	17,535,006
1830	64,645,342	4,133,741	19,428,664
1831	63,821,440	3,975,019	17,257,204

Cotton
weaving.

(984.) *Cotton weaving.*—We propose to treat of the Art of weaving in a separate article, after having described the methods employed for reducing various materials, as flax, wool, silk, &c., to a form proper for the weaver; and in order to complete our sketch of the history of the cotton manufacture generally, it is necessary slightly to refer to the process of weaving, which we accordingly have done in the following columns; but for a more particular description of weaving generally, the reader must consult the article above mentioned.

The old hand loom, which is still employed in many places where the worsted manufacture is carried on, is too well known to require a minute description. It consists of a large wooden frame with a roller or beam at one end on which the warp is wound, and another at the other end where the weaver sits, to wind up the piece as it is woven. The weaver sitting with his feet upon what are termed treadles, opens thereby with his treading the threads of the warp, and reaching at his full stretch, his breast bearing against a fixed beam, he throws the shuttle backwards and forwards with his hands, but alternately removing one of them to drive the weft or shoot up close with a swinging part called the boards or lathe. When the stuff was of so great a breadth that one man could not reach, then two men became necessary.

Such was also the form of the cotton loom till about the year 1738, when a great improvement was made by

John Kay. This consisted in lengthening the lathe sufficiently at each end to receive the shuttle in a box, instead of the weaver receiving it into his hand; and by means of two strings fixed to a movable piece in each box, the strings being united to a short peg in the centre, the workman by a smart jerk struck the shuttle from side to side with his right hand, while his left was steadily applied to the lathe. His position thus became upright and easy compared with the former constrained and leaning posture. By this invention considerably more work could be done, the thickness of the cloth was preserved more uniform, and the health of the weaver greatly improved.

Another improvement was afterwards made by the same person in what is called the drop box. This comes into application in those goods requiring two or more shuttles where the weft is of different colours, which required formerly the weaver to stop and change his shuttles after a certain number of throws, whereby much time was lost; but by Kay's contrivance the box contained the two shuttles, and by suddenly raising or depressing it any shuttle might be thrown, and in any order of succession, without any let or delay. This form of loom, with certain minor improvements in the lightness of the construction and neatness in the working parts, is that which is still employed by the hand-loom weavers, and will require no further description. We proceed, therefore, at once to an account or history of the invention of the power loom.

(985) *Power loom.*—It is remarkable that, the power loom being of such recent introduction, our first notice of it is so early as the year 1678, when a Paper was read to the Royal Society, and afterwards printed in the *Philosophical Transactions*, under the title of *A New Engine to make Linen Cloth without the help of an Artificer*, by M. de Gennes. This description, with an illustrative plate, is preserved by Dr. Hutton in his *Abridgement of the Transactions*, vol. ii. p. 439. It is needless, however, to enter into particulars of it in this place, as it was probably never more than a creature of the imagination, and was never attempted to be carried into real practice. It differs greatly, as may be supposed, from the present power looms, but the idea was the same, and in other times it is probable the ingenious inventor might have made it effect his intended purpose, which is stated to be, first, "that one mill alone will set ten or twelve looms to work; secondly, the cloth may be made of

Hand loom
and fly
shuttle.Power loom
projected in
1678.

Manufac-
tures.

what breadth you please, or at least much broader than any which has been hitherto made; thirdly, there will be fewer knots in the cloth, since the threads will not break so fast as in other looms, because the shuttle that breaks the greater part can never touch them. In short, the work will be carried on quicker and at less expense, since, instead of several workmen which are required in making of very large cloths, one boy will serve to tie the threads of several looms as fast as they break, and to order the quills in the shuttle."

Cart-
wright's
power loom.

(986.) An attempt, carried to a much more practical extent, was again made in 1765, by what was called the swivel loom, which was however soon abandoned; but in 1784 a close approximation to the present power loom was proposed by Dr. Cartwright, who has given the following account of the motives which first led him to the undertaking.

"Happening to be at Matlock in the Summer of 1784, I fell in company with some gentlemen of Manchester, when the conversation turned on Arkwright's spinning machinery. One of the company observed, that as soon as Arkwright's Patent expired so many mills would be erected, and so much cotton spun, that hands never could be found to weave it; to this observation I replied, that Arkwright must then set his wits to work to invent a weaving mill. This brought on a conversation on the subject, in which the Manchester gentlemen unanimously agreed that the thing was impracticable; and, in defence of their opinion, they adduced arguments which I certainly was incompetent to answer, or even to comprehend, being totally ignorant of the subject, having never at that time seen a person weave. I controverted, however, the impracticability of the thing by remarking, that there had lately been exhibited in London an automaton figure which played at chess. Now you will not assert, gentlemen, said I, that it is more difficult to construct a machine that shall weave than one which shall make all the variety of moves that are required in that complicated game.

"Some little time afterwards a particular circumstance recalled this conversation to my mind. It struck me that as in plain weaving, according to the conception I then had of the business, there could only be three movements which were to follow each other in succession, there would be little difficulty in producing and repeating them. Full of these ideas, I immediately employed a carpenter and smith to carry them into effect. As soon as the machine was finished, I got a weaver to put in the warp, which was of such materials as sail cloth is usually made of. To my great delight a piece of cloth, such as it was, was the produce. As I had never before turned my thoughts to any thing mechanical, either in theory or practice, nor had ever seen a loom at work, or knew any thing of its construction, you will readily suppose that my first loom was a most rude piece of machinery. The warp was placed perpendicularly, the reed fell with the weight of at least half a hundred weight, and the springs which threw the shuttles were strong enough to have thrown a Congreve rocket. In short, it required the strength of two powerful men to work the machine at a slow rate and only for a short time. Conceiving, in my great simplicity, that I had accomplished all that was required, I then secured what I thought a most valuable property by a Patent, 4th of April, 1785. This being done, I then condescended to see how other people wove, and you will guess my astonishment when I compared their easy modes of

operating with mine. Availing myself, however, of what I then saw, I made a loom, in its general principles nearly as they are now made. But it was not till the year 1787 that I completed my invention, when I took out my last weaving Patent August 1st of that year."

Subsequently, the inventor established a weaving mill at Doncaster, but it did not succeed; he obtained, however, from Parliament a grant of £10,000 as a reward for his ingenuity.

Another undertaking of the same kind by Messrs. Grimshaw, executed under Dr. Cartwright's Patent, failed, after trial at Knott Mills, Manchester, in 1790. Another was again made and abandoned in 1794 by Mr. Bell of Glasgow. In 1796, another Patent was taken out by Mr. R. Millar of Glasgow, which was adopted by Mr. John Monteith in 1801, and after indifferent and variable success was at length made to answer the intended purpose.

It appears that the greatest impediment to the more early success of the power loom was the necessity of dressing the warp as it unrolled from the beam. In the old hand loom this operation, which is intended to lay down smoothly the floss or feathers of the cotton twist previously to their passing through the reed, was effected by two long brushes which were dipped or covered with size or starch, the one being applied under and the other over the unwound warp which was brushed or dressed by the weaver, and when this part was nearly woven up another dressing was given, about yard by yard or a little more.

(987.) This operation was a great inconvenience in power-loom weaving, but it was at length fortunately avoided by giving to the warp a sufficient dressing in the first instance by a new invented dressing machine; and from that time every difficulty has been gradually vanishing, so that there is little doubt that the old hand loom will be ultimately wholly superseded. The dressing machine is due to a weaver of the name of Johnson, one of the workmen of Messrs. Radcliffe and Ross, of Bradford, at whose charge the expense of the experiments and Patent were sustained. The yarn is first wound from the cop upon bobbins by a winding machine, in which operation it is passed through water to increase its tenacity. The bobbins are then put upon the warping mill, and the web warped from them upon a beam belonging to the dressing frame. From this beam, placed now in the dressing frame, the warp is wound upon the weaving beam, but in its progress to it passes through a hot dressing of size. It is then compressed between two rollers to free it from the moisture it had imbibed with the dressing, and drawn over a succession of tin cylinders heated by steam to dry it; during the whole of this last part of its progress being lightly brushed as it moves along and fanned by rapidly revolving fanners. The dressing here spoken of is merely a size or paste made of flour and water, now generally used cold, and the use of it is to make the minute fibres which, as it were, feather the yarn, adhere closely to it so that the warp may be smooth like catgut. The brushes essentially aid in smoothing the yarn and distributing the size equally over it, and by means of the fan and the heated cylinders the warp is so soon dried, that it is wound upon the beam for the loom within a very short space after passing through the trough of paste. This machine, from the regularity and neatness of its motion and its perfect efficacy, is equally beautiful and valuable.

Manufac-
tures.

This mode of dressing rendered the power loom available, (although the process is now superseded by a simpler one in some establishments,) and successive improvements have at length, perhaps, brought it to its greatest attainable perfection. The first new Patent for a power loom, after the invention of the dressing frame, was taken out by Mr. H. Horrocks in 1803, further improvements in which were patented in 1805, and again in 1813. Another Patent by Mr. P. Marsland was enrolled in 1806; this had a double crank and made superior cloth, but was much more complex than the former, which is the one now principally adopted.

Estimated
number of
the power
and hand
looms in
England
and Scot-
land.

The number of power looms in England and Scotland has been increasing from the date of the last Patent, in 1813, in a surprising degree, as will appear by the following statement given by Mr. Baines, from whose Work the following abstract has been formed.

Number of Power Looms in England and Scotland in the Years 1820, 1829, and 1833.

1820, Number of power looms in England	12,150
Ditto Scotland	2,000
1829, Number of power looms in England	45,500
Ditto Scotland	10,000
1833, Number of power looms in England	85,000
Ditto Scotland	15,000

With this wonderful increase in the number of power looms, it is extraordinary that the number of hand looms are not diminished, but seems rather to have increased. The number of the latter in 1820 was estimated by Mr. Kennedy at 240,000, and in 1833 they were stated by Mr. Grimshaw at 250,000. See *Parliamentary Report on Manufactures*, p. 608. This exceeds, however, the estimate made by Mr. George Smith, at p. 566 of the *Report*, who considers them as only amounting to 200,000, but Mr. Baines inclines to the former estimate as the most probable. The number of hand looms in Scotland, in 1834, appears to have been about 45,000 or 50,000.

With respect to the work that can be performed with these power looms as compared with the work that can be done by the hand loom, and the increasing quantity which every successive improvement enables the power loom to perform, the following was given by a manufacturer to Mr. Baines as a correct statement.

"A very good *hand weaver*, twenty-five or thirty years of age, will weave *two* pieces of $\frac{2}{8}$ shirtings per week, each twenty-four yards long, containing 100 shoots of weft in an inch, the reed of the cloth being a forty-four Bolton count, and the warp and weft forty hanks to the pound.

"In 1823 a *steam loom weaver* about fifteen years of age, attending two looms, could WEAVE seven similar pieces in a week.

"In 1826 a *steam loom weaver* about fifteen years of age, attending two looms, could weave twelve similar pieces in a week; some could weave fifteen pieces.

"In 1833 a *steam loom weaver* from fifteen to twenty years of age, assisted by a girl about twelve years of age, attending to four looms, can weave *eighteen* similar pieces in a week; some can weave twenty pieces."

TABLE showing the Number of Yards, printed and plain, of Cotton Goods exported from the United Kingdom, with their declared Value, from 1820 to 1831.

Year.	WHITE OR PLAIN COTTONS.	
	Yards.	Declared Value.
1820	113,672,486	£5,451,024
1821	212,921,692	5,713,722
1822	142,162,131	6,317,973
1823	152,184,867	5,884,935
1824	170,091,384	6,437,817
1825	158,039,786	6,027,892
1826	138,159,783	4,477,942
1827	183,940,186	5,762,576
1828	189,475,956	5,623,802
1829	222,504,344	5,853,625
1830	244,799,032	6,562,397
1831	239,191,271	6,065,478

Year	PRINTED OR DYED COTTONS.	
	Yards.	Declared Value.
1820	13,469,117	£7,742,505
1821	141,412,002	7,454,243
1822	158,998,957	7,480,634
1823	149,631,387	5,095,709
1824	174,559,749	8,010,432
1825	178,426,912	8,205,117
1826	128,897,111	5,388,592
1827	181,544,618	7,184,459
1828	173,852,475	6,859,447
1829	180,012,152	6,662,623
1830	199,799,466	7,557,373
1831	182,194,032	6,098,035

We shall here conclude our sketch of the history and extraordinary progress of the cotton manufactures of Great Britain, and shall now endeavour to describe concisely, but with a little more detail than could be introduced into the preceding pages, the successive steps of this manufacture as they are pursued in the most improved modern establishments.

Description of the Processes employed in the Cotton Manufacture.

(988.) In the preceding historical sketch we have spoken only of those branches of the cotton manufacture in which great and important inventions have been employed to perfect and expedite several of the mechanical processes, but we have not entered into minutiae, nor have we attempted to describe the several steps *seriatim* as they are now practised in our larger mills; this will be the subject of the following articles.

The pods of cotton are opened in the Country in which it grows, whether Egypt, America, or India; the wool is then packed into large bags, in which it is received at the cotton mill in Manchester or elsewhere. It has then to undergo the following processes; *viz.*, it has to be batted, carded, and formed into slivers, doubled, drawn, roved, spun, and wove, requiring intermediate operations which will be described as we proceed.

Mechanical
Processes.

Processes
described.

Manufactures.
Cleaning and batting.

(989.) *Cleaning and batting.*—The first operation the cotton has to undergo, after being unpacked, is to clean it from all the seeds or motes it may contain previously to its being carded. This was formerly performed wholly by hand, and is still so in some manufactories and for certain goods. A long frame, about the height of a common table, is formed, with sides and a bottom, of parallel cords laid pretty closely, and upon this the cotton wool is laid, opened a little by the hand and then beaten by the batter, who uses a light willow stick in each hand, and as he raises the sticks he opens and shakes the cotton, thereby clearing it of the seeds and other dirt, which fall through the corded bottom of the batting frame. But this operation, except for the finer cotton, is now effected by machines; there are several kinds, of which the following is perhaps the best.

Batting and scutching machine.
Pl. lxix.
Fig. 1

This machine, represented in plate lxix. fig. 1, resembles in some measure the thrashing machine. The cotton is fed through rollers, and struck by scutchers moving at a great velocity, which operation opens the cotton, at the same time it is blown by fanners, which serve further to open it, and to separate the lighter and finer parts, while the gin or seeds, sand, &c. are driven or fall through a grating made of wire.

The cotton, as taken from the bag, is spread on the feeding cloth A B, which conveys it forward to the feeding rollers. C E are two of the scutchers which, moving at a great velocity in the direction expressed by the arrow, strike and open the cotton as it is fed in by the rollers, while a strong current of air, produced by the motion of the fanners G H I, acts upon it. The gins, sand, &c. are driven through the circular grating L M, and fall on the angular grating N O. Q R is a long grating which is level, and through which any remaining lumps or gins pass, while the cotton is blown forward to a small apartment or closet from which it is from time to time removed. For fine spinning it is then ready to be picked by hand to take out any remaining motes, but for ordinary spinning it is taken immediately from the batting machine to the carding engine.

This improved batting machine not only saves much labour and expense, but, from the manner in which the cotton is enclosed during the operation, much dust, film, &c. is prevented from escaping, which, as the process was formerly conducted, was most prejudicial to health.

The scutcher is 14 inches in diameter, and makes from 1200 to 1400 revolutions per minute. The feeding rollers, one and three-fourth inches in diameter, go one revolution for sixty of the scutchers. The fanners, twenty-two inches in diameter, have the same speed as the scutchers. The circular grating under the scutchers is one inch in diameter in the wires, all the others have their wires about three-eighths of an inch distant from each other.

Carding and carding machine.
Fig. 2, 3, 8, 9.

(990.) *Carding.*—The next operation is that of carding, by means of which the cotton, opened and cleansed at the batting or scutching machine, is carded or combed, the fibres spread and laid evenly and parallel to each other. To the several improvements in this process we have had occasion to refer in our historical sketch. We have seen that this operation was first performed by hand cards, then by double cards, stock cards, and then by machinery with plane cards, then by cylinders; but in all cases the carding was removed by hand, in cardings the length of the card or cylinder, then the same was produced by an apparatus attached to the machine, till at length Arkwright took out his Patent for continuous

carding which produces the sliver in one long length. A representation of this machine in its most improved form is given in plan and elevation in fig. 2, 3, where A is the large cylinder covered with cards, (see description, p. 310,) the sheets of leather for which are glued or nailed on in strips or sheets parallel to its axis, and disposed in such a manner that when the cylinder revolved in the direction of the arrow the teeth upon it, see fig. 8, 9, go with their points forward, so that if a piece or knot of cotton were held against them it would be drawn inwards upon the teeth. This cylinder is driven by a band passing over the pulley or drum R, being connected with the first mover, whether it be a water-wheel or steam-engine. This cylinder revolves under an arch C C, fig. 3, lined with the same kind of cards, the teeth being so disposed as to meet those of the cylinder; this is supported on two iron arches fixed on each side of the cylinder, these having spokes on them on which the several pieces that form the arch are fastened.

B is a second cylinder of cards, these being laid in spirals, revolving much slower than the former, its motion being communicated by wheelwork driven by a wheel on the axle of the larger cylinder A; D is the feeding cloth on which the cotton received from the scutching machine is spread; this traverses constantly round two rollers which are likewise turned by a communication with the wheel on the axle of the principal cylinder. The cotton being spread on the feeding cloth as above described, and the machinery put in motion, it advances slowly with the cloth and is thus thrown in between the two feeding rollers which deliver it gradually and equably to the carding cylinder, which carries it round and works it against the fixed cards under the arch C. In this process it becomes very equably distributed over the teeth of the cylinder. The cotton continues thus hanging sometimes in the teeth of the cylinder and sometimes in those of the arch, but advancing slowly from one tooth to the next till it has passed clear through the arch, when it comes to the small cylinder B, which, as already stated, is revolving slowly in such a direction that its surface moves the same way as the cylinder but much slower, and its teeth meeting those of the cylinder. The teeth of this small cylinder having no cotton upon them receives about half what is upon the teeth of the cylinder A, and as it constantly turns round and brings up fresh empty teeth, these in their turn take away the cotton, so that it is continually carried from this in a uniform stream, which is as uniformly supplied by the feeding cloth and rollers. The cotton thus received upon the cylinder B proceeds downwards with it, but as it again ascends, a *taker off*, which is a sort of steel comb, keeps continually stripping off the fleece by an alternate and rapid motion, so as to remove it from this cylinder in a continuous fleece; this fleece is sometimes again spread on the feeding cloth of a similar machine, and is in the second process carried, in the form shown in the figure, through two rollers to compress it, and is then delivered into a tin can or cylinder S placed to receive it.

(991.) *The drawing frame.*—The next process is that of doubling and drawing, the machine for which is represented in fig. 4, 5. The object of this is to combine and recombine several slivers into one, and at the same time to draw and lengthen them, to equalize the thread, and to render it of more uniform strength and texture.

The drawing frame, fig. 4, is of itself so explanatory of the process as scarcely to require any description:

Mechanical Processes.

Drawing frame.
Fig. 4, 5.

Manufac-
tures.

A, B, C, &c. are cans brought from the carding engine; the sliver in each is passed through two or three pair of drawing rollers *ee, ff*, &c. the latter moving with four or six times the velocity of the first pair; this reduces each sliver proportionally less than its original size, but the whole being ultimately united by passing through the funnel *g* seen in the figure, they fall in one combined sliver into a can as before, the fibres by this process having been further straightened, and any inequality in the first sliver thus reduced. This operation is performed several times, but greater or fewer, according to the quality of the goods intended to be manufactured; on some occasions it is repeated, till each sliver contains portions of several thousands.

Roving
apparatus,
or roving
billy.

(992.) *Roving machine*.—This, like most of the other machinery, has passed through many forms, and has received different denominations; the object of the operation is to reduce the sliver as obtained by the doubling and drawing machine into a finer sliver or roving, and to give it such a twist as shall reduce it to the form of a large coarse line or yarn. In this process the sliver is made to pass through pairs of rollers, which, differing from each other in speed, draws them out finer and to a greater length, and ultimately to give to the roving the twist requisite to fit it for the process of spinning. The first idea was to receive it into cans, which were themselves revolving by a detached portion of the engine power, and by means of which the thread was twisted as it fell into the can, and the operation was accordingly denominated can roving, and it is still practised in some manufactories. Another process has been denominated the jack-frame roving, and another the spindle and flier roving; which latter being now commonly adopted is that we propose to describe. The roving frame is of considerable length, carrying on one side a number of spindles, on which are placed bobbins to receive the rovings after they have acquired the twist which is the object of this operation; the cans from the doubling and drawing machine are arranged on the other side, and the sliver of each is brought from the can, passed through rollers, and thence through a flier on the top of each bobbin, as represented in fig. 6: one branch of this flier is tubular, marked *g*, and through this the sliver is brought to the bobbin. The machine being now put in motion, the twist is given to the sliver by the revolving of the flier as it enters at *r*, and is drawn forward at the same time through the tubular part *g*, by winding on the bobbin *p*, the bobbin and flier revolving with different velocities, the former being loose on the spindle which carries the flier. The bobbin is made to revolve by a band passing over the pulleys *ii* on which it rests, and the spindle and flier by a band passing over the pulleys *hh*. It will be observed that, as the roving is always winding from the lower end of the flier *g*, it is necessary that the bobbins should be made to ascend and descend as they revolve, so that the roving may be laid evenly and smoothly upon them. This rising and falling motion is produced in different ways. According to the plan indicated by the drawing, it is effected by the gradual ascent and descent of the bar *NN* on which the pulleys rest, and which is shown in the figure referred to; by this contrivance the roving falls close to but not upon the former turn, thus disposing it regularly through all the length of the bobbins, and when the latter have descended to the lowest point, they gradually rise again, then fall, and so on, till they are filled and removed

by the boy or girl attending to the machine, whose business is then to supply other bobbins, and to unite any of the rovings that may separate as the operation proceeds. The can roving differs from the above only in this, that instead of the roving being wound on bobbins it was allowed to fall into a can and to receive its twist by the revolution of the can. The latter process was that first adopted by Arkwright, but for which he afterwards substituted the spindle and fly, in which the great difficulty to be overcome was that the bobbins, when they became filled with rovings, being much heavier than when empty, required much more force to drag them round. The bobbin at first was made to rest on the rail *N*, and was retarded from moving so fast as the spindle by friction only. Had it moved equally fast with the spindle, it is obvious it could not have taken up the roving, and had it been stationary, the flier would have had the effect of stretching and breaking the roving. The bobbin, therefore, required to have a motion, but a slower one than the spindle, and that motion also required to become slower as the bobbin filled, in consequence of the greater circumference. All these difficulties are, however, avoided in the present roving machine, by means of the double motion or speed given to the bobbin and spindle as above described. We have already stated, that at every revolution of the bobbin the rail *N* gradually rises, and then gradually falls; besides which, it will be seen from what has now been stated, that it is necessary after each ascent and descent that the speed of the bobbins should be made proportionally slower, that the quantity wound up in a given time or in a given number of revolutions may be the same, and consequently the stretching force on the roving the same also.

The mechanism, by means of which this change in the velocity of the bobbin is accomplished, is different in different mills or in different machines. We may shortly describe the two methods most approved. In some machines it is produced by means of two conical barrels of the same dimensions, but placed with the larger end of the one opposite the smaller end of the other. The one of these barrels, moving uniformly, communicates motion to the other by an endless strap, which, by being shifted towards either extremity, varies the motion of the other barrel. The belt or strap remains equally tight in every part, for the one barrel increases in diameter exactly as much as the other decreases. From the second barrel motion is conveyed to the pulleys resting on the bearer *NN*, and having the spindles passing through the centre of each; the bobbins rest on those pulleys, and are carried round with them.

In other machines, instead of the conical barrels, two wheels having no teeth but covered with leather, the one bearing on the face of the other, moves it by contact, and varies the motion by approaching and receding from the centre of the face wheel. For a more particular account of these two pieces of mechanism, and other similar contrivances, see article (77.) of the present Treatise.

(993.) *Jenny spinning*.—The cotton being prepared by the preceding processes is now in a state for spinning either by the roller, or as it is commonly called water-spinning, or by the mule; but for jenny spinning, the doubling and drawing process is not essential. We have already referred to this mode of spinning in our historical sketch, and to the trifling accident which gave

Mechanical
Processes.

Manufac-
tures.

rise to it; it in fact very much resembles the hand spinning, but is so contrived that one person works a number of spindles at the same time; it resembles also in some measure the roving billy, but differs from it in construction in this respect, that the clasp is attached to the carriage while the spindles are disposed on the rails of the frames which remain at rest. The drawing out of the clasp stretches the rove so as to reduce it to the size proper for the yarn, at the same time the spindles twine it. During the return of the carriage, the yarn is built on the spindles by levers and wires and formed like the rovings in the roving billy into cops, which are afterwards drawn off the spindle, as with the common spindle and distaff. It is wrought by hand by one person, who is assisted by a boy or girl called a *piecer*, whose business is to mend such threads as break. The yarn when taken off the spindle is sometimes reeled, but more frequently given to the weaver in cops, who has it wound on the bobbins or *pirns* preparatory to its being placed in the shuttle. Common jenny spinning is now but little used except for the web of calicoes; for this purpose it is preferred to that produced by the mule, as it gives the cloth a more rich and full appearance.

Roller spin-
ning.
Fig. 7.

(994.) *Roller and fly or water spinning*.—This we have already described in a general way, in speaking of Arkwright's invention; it remains now to describe it a little more in detail, leaving out of consideration the disputed claims to the actual discovery. Of the nature of the operation a general idea may be formed from the preceding description of the roving machine with spindle and flier; but as the thread in spinning has sufficient strength to bear the drag of the bobbin, no mechanism for regulating the speed of the latter is in this case necessary, so that the bobbin resting on the rail or bearer is retarded by friction only. We have represented one single thread undergoing the operation of spinning, in plate lxix. fig. 7, availing ourselves in this case of the description given of it by Mr. Duncan, in the *Edinburgh Encyclopædia*. A is the binder or pulley loose on the axle C D. This binder is kept in motion by a broad belt from a drum on an upright shaft of the millwork; E is the fast pulley fixed on the axle C D. In order to disengage and re-engage the axle C D from the fast pulley E, and thereby to stop or set going the head of spinning connected with it, the locking bayonet is used. This, which is described at article (51.) consists of a kind of fork *abcd*, which passes through two holes in the fast pulley E. The bayonet is movable upwards and downwards on the axle C D, which passes through its collar *c b*. Round this collar there is a groove, into which part of what is called the *lifter* projects, and by means of which the bayonet is by hand at pleasure raised or depressed. While the bayonet is in the situation represented in the figure, the binder A keeps running on its bush, and the axle C D is at rest.

In order to set the axle in motion, the bayonet is depressed, and its leg *a* and *d* lay hold of two projecting teeth or pieces of iron, in a groove in the upper end of the binder A. The fast pulley E is thus locked or connected with the binder, whereby the axle and pulley are carried round together, and thus motion is given to the whole of the moving part of the thread. This contrivance is also used for disengaging the drums on the upright shafts of the millwork, and was also used in Arkwright's can roving frames, and various other parts of cotton machinery; but the fast and loose pulley

already described has now in many instances superseded the bayonet, to which it is to be preferred in all situations where circumstances will allow of its application, as by it the belt carries the pulley into motion without any shock. A great improvement on the locking bayonet has, however, of late years been introduced. Instead of making it, when thrown into gear, strike against permanently fixed teeth, or a fixed *clutch*, it strikes against the ears of an iron hoop which embraces a fixed pulley, and thus prevents the machine being so suddenly jerked into motion when the bayonet is let down. See the article *MILLWORK*, p. 101. The elementary process of drawing (or further reducing the roving into a size proper for a fine thread) is performed in the spinning frame by fluted rollers similar to those of the roving frame, to which motion is given in the following manner. On the top of the axle C D is a pinion F which works into a face wheel, represented by a dotted circle, (in order that the rollers may be better seen, of which a vertical section is shown in the figure,) fixed on the end of the front roller *e*, from which, by a train of wheelwork, motion is communicated to the middle roller *f* and the back roller *g*. This train of wheelwork is calculated so as to produce the requisite drawing effect. Between the middle and back rollers there should be a little more draw than is necessary to pull the rove from the back rollers, for it is found that the thread is more even when the fibres are pulled by the front rollers. The back rollers serve to keep the roving from being pulled too fast forward; the top roller *h*, in the middle, is much lighter than the other top rollers, and permits the fibres to move freely among themselves in reducing the roving. G H represents the spindle, to which motion is communicated from the fast pulley E, by means of a strap formed of cloth listing I K, which goes round the spindle shaft at I; *i k l* is the flier, the legs of which consist of two solid pieces of iron, twisted somewhat like a corkscrew at the lower extremities, in order to conduct the thread to the bobbin.

The operation of this machine will now be easily explained. The bobbin containing the roving L is placed in a frame behind, from it the roving passes to the back rollers *g, p*, through a wire eye *o*, fixed in a wooden rod *r*, but has a slow reciprocating horizontal motion, the use of which motion is to make the roving traverse a little on the rollers, to prevent it from wearing them, or wearing the leather too much in one part. The roving being reduced in its passage between the three sets of rollers proceeds through the leader *q* (which is an eye formed of wire fixed in the leader board) to the flier, which twists and lays the thread on the bobbin *m n*, in a similar manner to what has been already described of the flier used in the roving frame. The ascending and descending motion of the bobbin for laying the thread regularly is produced as follows: a wheel in the form of a heart, called the heart-wheel, moves with a regular vertical motion and acts on a roller, which, by means of levers, alternately raises and depresses the bobbin rail M. This rail has pieces of thin wood *x y* projecting from it, which go under the bobbins, and on which pieces they rest and are moved along with the rail; the motion is so calculated that when the bobbin is full of yarn it is swelled a little somewhat into a barrel form; moreover the bobbin (as was described in the roving machine) does not revolve with the velocity of the spindle; but in this it is retarded by friction, which is increased to the requisite

Mechanical
Processes.

Manufac-
tures.

degree by means of washers of cloth or leather; so that the thread by the motion of the flier drags the bobbin about after it, with a velocity equal to the difference between the motion of the flier and the motion of the thread delivered out by the front rollers. The thread is sufficiently strong to bear without injury the drag of the bobbin, and, therefore, as before observed, it does not require the mechanism to regulate its motion which is necessary for the rovings. When the bobbins are full the attendants take them off the spindles. The dexterity with which this work is done, as well as that of the mending the threads, (for which last purpose it is not always necessary to stop the spindles,) always appears extraordinary to those who for the first time witness these operations.

The bobbins when taken off the spindles filled with twists for warps are carried to be reeled, but stocking yarn undergoes the operations of doubling and twisting. This last kind of yarn is softer than common twist, and requires to be more even, because, in a stocking, the whole of the texture at any one part is formed by the same thread, and any defect will make a bar in the stocking, whereas, in cloth, so many different threads cross each other in one place that a defect in any one is seldom perceptible in the cloth. In order to obtain greater evenness, stocking yarn is usually spun from double rovings, wound on the same roving bobbin, and the roving can frame is still used in the preparation for this kind of spinning.

Spinning
with the
throstle.

(995.) *The throstle*.—The throstle is a machine resembling the one last described in the general nature of its action, but it differs from it in this, that instead of heads, each of which may be stopped independently of the rest, the whole of the rollers on one side of the frame are connected, and the whole of the spindles on both sides are driven by means of bands of lists from one cylinder which extends the whole length of the machine. This receives its motion from a belt, and from its axle motion is communicated by wheelwork to the rollers. The cylinder is stopped and put in motion by the fast and loose pulley, but there is an inconvenience in it, that it cannot be stopped for one head without stopping the whole machine. In other respects its advantages are, that it is more simple, consists of fewer parts, and is of course less expensive. It is at present, perhaps, undecided on which side the balance of advantage preponderates.

Mule spin-
ning.

(996.) *Mule spinning*.—We have already, in our historical sketch, given an idea of the general principle of action of the mule-jenny, *i. e.* that it receives the thread from the roving bobbins, passed through rollers to draw it, resembling thus the roller-spinning machine; but instead of receiving the thread when spun on bobbins, it is built in cops on spindles, in which it resembles the jenny; but it differs from both in so far as it stretches as well as spins the thread after a certain quantity has been delivered from the roving bobbin through the drawing rollers. To effect this, the carriage which carries the cops runs backwards and forwards on wheels formed like a pulley on an iron edge or railway, the motion amounting to about four feet and a half; and when about three feet of the drawn roving has been delivered, the delivery is stopped, and the remaining half yard of the carriage motion is employed in stretching the thread, which by this means is obtained much finer than by any other machine which has been yet invented.

This general description will be better understood by

referring to fig. 1, plate lxx. which represents a detached cop G, thread *t*, and bobbin W. The spindle D is fixed in the movable frame above mentioned, while the bobbin W and rollers A, B, C are fixed in their places. Conceive the carriage carrying the cop G to be wheeled up to its nearest position to the rollers, the thread being wound upon the cop. This is now run back at exactly the rate which the rollers deliver the thread from the roving bobbin, being at the same time twisted by the revolution of the spindle carrying the cop; but when the carriage has retreated about two-thirds of its whole distance, the delivery is stopped, and by the subsequent retreat of the carriage the thread is stretched and rendered so much the finer. This being done, the spinner in the hand mule, or the machinery in the self-acting mule, shifts the thread from the point at which it had received its twist to the middle of the cop, and as the carriage is run up, the motion of the spindle is such as just to wind up the length of thread last spun upon the cop; the thread is then again fixed to the end of the cop as before, and the same operation repeated. The shifting of the position of the thread from the position in which it receives its twist to that in which it is wound on the cop, is simply by the action of a wire pressing upon it as shown in the figure by I, H, which turns on the axis I in order to effect this object.

It is impossible in a Work like the present, which pro- fesses to give only a general view of the machinery of Great Britain, to afford sufficient space to describe, at the length which is necessary for a full comprehension of this complicated engine, all the admirable contrivances, adjustments, and proportions requisite for its due action; we shall therefore content ourselves with giving a side view of a mule-spinning engine of the most modern construction, fig. 2, trusting that the reader, by comparing it with the description of its action as above given, will be able to form a pretty correct general idea of its mode of operation.

(997.) *Reeling machine*.—This is an exceedingly simple machine, and the operation is also very simple. It consists simply of a reel with four or six sides, in the form therefore of a square or hexagon, formed by four or six long rods or bars lying horizontally, and which is turned by hand or by machinery, to wind off the thread from the bobbins into the form of hanks, from a row of bobbins placed on the side of the frame. The reeler begins by making all the ends of the threads fast to one of the rails; the reel is then turned, either by the engine or by hand, and when it has made eighty revolutions, which is called a lay, a bell or click strikes, the reel is stopped, and each lay is tied with a piece of thread in order to keep them distinct; and this being repeated seven times, each seven lays form what is called a hank, and the whole is then taken off the reel and the operation repeated. To facilitate the removal, one of the sides of the reel turns on a hinge; this being put down, the hanks become loose and are easily removed.

This concludes the duty of the cotton spinner: the remaining processes belong to the warper, the weaver, bleacher, dyer, and dresser.

In concluding our description of this department of the cotton manufacture, we may be allowed to observe, that in order to make the reader acquainted with the several processes, it has been thought best to illustrate each by the operations on a single thread; which, however, while it renders the conception of the Art more easy, gives no idea of that which strikes a visitor with

Mechanical
Processes.
Pl. lxx.
Fig. 1.

Fig. 1, 2.

Reeling
machine.

Manufac-
tures.

most wonder when he enters the manufactories in which this business is conducted, that is of the extraordinary extent, the triumph of ingenuity, the cleanliness and order which prevail in these several establishments, many of them from five to seven stories high, on floors some hundreds of feet in length, where instead of the single threads represented in our figures, several thousands of such threads are under the continual process of being formed, without labour and without noise; the little girl or boy attendant is at his post to watch the operation of some hundred threads, and whose only business is, when any one by accident breaks, to mend it, or to remove the bobbin or cop when filled, and to replace it. In general, the batting and scutching is carried on on the upper floor, then the carding, then the roving, spinning, reeling, &c., in succession, so that the least possible time may be wasted in removing the material from one machine or process to the next; the whole of the labour being performed by some huge steam-engine or water-wheel in a remote part of the building, the hands which are employed being simply to guide, to stop, or to put in motion this great primum mobile of the whole.

Darwin predicted much which steam has since been made the agent to effect, and we do not think we can more appropriately close our present article than by presenting his lines to the reader.

Where Derwent pours his dusky floods
Through vaulted mountains and a night of woods,
The nymph *Gossypia* treads the velvet sod
And warms with rosy smiles the watery god;
His pond'rous arms to slender spindles turns
And pours o'er massy wheels his foaming urns;
With playful charms her hoary lover wins,
And wields his trident while the monarch spins.
First with nice eye emerging Naiads cull
From leathery pods the vegetable wool;
With wiry teeth revolving cards release
The tangled knots and smooth the ravelled fleece;
Next moves the iron hand with fingers fine,
Combs the wide card and forms th' eternal line;
Slow with soft lips the *whirling* can acquires
The tender skeins, and wraps in rising spires;
With quicker speed successive rollers move,
And these extend while these retain the rove;
Then fly the spokes, the rapid axles glow,
While slowly circumploes the labouring wheel below.

Weaving being nearly the same, whether the cloth be cotton, flax, silk, or other matter, will be best illustrated after describing the several processes by which these different materials are reduced to a form ready to be submitted to this final operation.

Hemp and Flax Manufacture.

Manufac-
ture of
hemp and
flax.

(998.) This manufacture, till of late years, was conducted nearly on the same principles as the original cotton and worsted manufactures; the hemp or flax, after having been prepared, was spun by the wheel and spindle; it was afterwards warped and woven by the handloom, differing only in a trifling degree from the looms used in general for all kinds of cotton and worsted stuff, &c. The great mechanical improvements, however, introduced into the cotton manufacture have led the way to the adoption of similar processes in spinning and weaving hemp and flax, which of course differ in degree, but only in degree, from those we have already described at length under the former article. If we aspired in this Work to describe machines and processes in such detail as to give actual information to manufacturers, it would be

VOL. VIII.

Mechanica
Processes.

necessary to make a distinct article of flax-spinning from that of cotton-spinning; but we do not attempt this task; our object being simply to give to the general reader a tolerably correct idea of these interesting operations, and which differ so little in this point of view from each other as to render a minute description of flax-spinning and weaving unnecessary. The preliminary processes, however, by which the cotton, hemp, and flax are prepared for spinning, are essentially different, in consequence of the different nature of these vegetable productions; this, therefore, requires to be described; and in doing this we shall avail ourselves of a very valuable article on the subject by Mr. Millington, published in vol. xxxii. of the *Repertory of Arts*.

The flax plant is an annual, requiring to be sown with the seeds of the last year's produce from the second week in March to the middle of April. It succeeds best in a free open loam, which is neither subject to too much wet or drought: it is certain of producing a good crop on new ground, and will generally thrive on any soil which is proper for barley or oats. It remains on the ground till the end of July, or the middle of August, when it ripens, and is fit for pulling, (unless it should from circumstances be desirable to keep it for seed only,) and may be succeeded by a crop of wheat or turnips, for which it is an excellent preparation. It may also be sown to advantage with clover seed, which will then succeed it as an after crop. Hemp is a much more rank and coarse plant than flax, growing from six to sixteen feet in height, and is more or less common in all Countries. It is, however, chiefly cultivated in the Northern parts of Europe, whence it is largely imported into England. It thrives well in England; and English hemp, when properly manufactured, is found more compact, strong, and durable than that of Russia. It should be sown about the same time as flax, in a deep, rich, moist soil, on which account the Isle of Ely and the fens of Lincolnshire are particularly favourable to its growth. Like flax, when sufficiently ripe, it is not cut but pulled up root and all, on account of which both these plants leave the soil particularly clean.

The first operation is to obtain the useful fibre from these plants, which is situated between the interior wood and exterior bark of each stalk, and has commonly been obtained by an aqueous decomposition, or by rotting away the wood and exterior bark by exposure to moisture, since the fibre itself (though no doubt somewhat injured by the process) has sufficient strength and durability to withstand it in a great measure. The process of rotting away the woody from the fibrous parts of the plants is one of extreme antiquity, it being noticed in the Sacred writings, and having been used not only in this Country, but on the Continent, from time immemorial; notwithstanding which, it has proved extremely detrimental to the health, not only of the inhabitants but of the cattle of those Countries in which it is carried on to a considerable degree, and is a system which, on this account, it would be highly desirable to abolish. It becomes the source of many pestilential diseases, among which perhaps the malaria, so prevalent in the vicinity of Rome and Naples, may be numbered; besides which, since flax and hemp ripen about the month of August, and require to be submitted to this process as soon as they are taken from the ground, or at least before they dry, the farmer's attention becomes necessary to them, at a time when it is most valuable and can least be

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Manufac-
tures.

spared, namely, in the time of, or immediately antecedent to, his corn harvest.

Water-ret-
ting.

(999.) The operation of rotting, or as it is most commonly called, water-retting, flax and hemp, is one of considerable nicety and hazard to the cultivator, on which account it has, in all probability, proved a much greater barrier to the cultivation of these useful plants in England than the alleged exhaustion of soil, or any other cause; for its perfection, and the period when it should cease, depend on several fortuitous circumstances, which may dispose the woody matter of the stem to decompose with greater or less facility. Thus it will be influenced by the strength and vigour of the plant, the moisture or dryness of the season, the temperature of the air during the process, as well as the soil from which the plant was produced. If the operation is carried too far, not only the woody matter, but the fibres also, will be destroyed or injured; and if not far enough, it has generally been thought that the flax will not dress; and thus, after a good crop has been produced, it may be much injured, if not spoiled, in the incipient stage of its manufacture.

The steeping or watering of flax is most commonly performed in artificial ponds or canals excavated by the sides of rivers, and generally about forty feet long, six feet wide, and four deep, a sufficient size to admit the produce of an acre of land at once. Sluices are so disposed that the contained water can at any time be let off, and a fresh quantity of water, which should be soft, admitted. These canals should be exposed to the sun, which assist the decomposition. The fresh gathered flax being tied in bundles or handfulls is carefully placed in these reservoirs, the upper bundles causing those which were first deposited to sink; and in this way each reservoir is filled, but not to such a degree as to force any part of the flax to touch the bottom; and when filled, the whole surface is covered with close hurdles or boards, and sufficiently loaded with stones to cause every part of the flax to be under the surface of the water. In this state it is left, and occasionally examined, to ascertain how far the process of decomposition is completed, which will generally be within a fortnight. The bundles of flax, which have by this time become very tender and difficult to handle, are now to be taken out on boards or trays and removed to the nearest short grass or heath, where they are regularly disposed in rows to lose their moisture, and in which situation they receive an additional preparation from the evening dews and occasional showers completing the decomposition, and at the same time washing away the slime and mucilage with which they are mixed. This last exposure is called dew-retting, and continues, according to the state of the atmosphere, for four or five weeks, or until the flax is as dry as it can be got, of a clean good colour, and all the woody matter which remains is perfectly brittle. The fibre will still retain most of its original tenacity, if the operation has been carefully and skilfully conducted. It is then carried away like hay, on a fine dry day, and deposited in barns, being now ready for the next process, called breaking and dressing, which is the separation of what is commonly called the *boon* or woody matter from the *harle* or useful fibres; and this may be effected in various ways. It is done in mills by machinery, and by hand, and in almost all cases is very effectually performed by a set of blunt iron teeth or breakers fixed upon one piece of wood, and met by another similar set

Dew-ret-
ting.

of teeth fixed to a movable piece, which is worked by the one hand, while the flax in handfulls is introduced between these teeth in various directions with the other hand. This breaks and knocks off the greater part of the wood in small fragments called chaff; and the operation is completed by *scutching* or beating the flax against a smooth post called a scutching post, and also beating it with an instrument somewhat resembling a curry-comb, and called a hand-scutch, by which the few remaining fragments of wood or boon are taken away, and nothing but the long fibre remains; which is now to be hackled or drawn by the hand over a species of comb, having a great number of very sharp, long, and perpendicular steel points upon it, by which any remaining boon and the short fibres or tow are removed, and the long fibres which remain are regularly disposed and ready to pass into the hands of the spinner.

(1000.) *Dry dressing.*—Much inconvenience having been experienced by the retting system, it was long considered a desideratum to effect the same with the plant in its dry state; and at length a process was discovered by Mr. Lee, of Old Ford, in Essex, in 1812, for which he obtained a Patent under the peculiar privilege, granted by Act of Parliament, of having his Patent sealed for the first seven years. The Patent also extended to other processes in the subsequent operations; but valuable as the first part of Mr. Lee's discovery may be, it does not appear that the machines he employed in the subsequent processes, in the first instance, were so successful as he had anticipated. One, which he calls a scraper, consists of a piece of timber supported like a stool, and firmly fixed to the ground at about two feet and a half from it, and laying in a horizontal direction; upon one end of this stool were fixed a few blunt iron teeth, or breakers, about eight inches long, in the direction of the length of the stool, and with their edges pointing upwards; another similar set of teeth were fixed in the same direction, but pointing downwards, at the end of a lighter piece of timber, which at its opposite end was attached by a strong hinge or joint to the top of the stool; and above this a handle to lift it up or press it down by the left hand, while a handful of raw flax was held in the right hand, and introduced between the upper and lower set of teeth or breakers, where it was to be turned and moved backwards and forwards, and occasionally drawn from between the teeth, which were, during this time, kept in a chopping action, and with a due degree of pressure, (so as not to cut or injure the *harle*,) by the motion of the left hand. This machine so nearly resembles the common hand breaker which has long been used in all Countries, that no representation of it is deemed necessary. When the flax had been thus sufficiently broken and scraped it was carried to another, the breaker, very similar in action but rather different in form to the first. In this, one set of breakers or iron teeth were fixed to a short horizontal piece of timber, but instead of pointing upwards they were fastened to one side of it, their length still being in a horizontal direction. This bearer for the breakers had its two ends mortised into two strong upright posts of timber about two feet asunder, the bottoms of which were fixed to the floor, and their tops to the ceiling of the room in which it was to work; the transverse piece carrying the breakers being fixed at such height between them as to be conveniently under the hand of a person standing behind it to work it, and the breakers, which were more in number and smaller than in the machine

Dry dress-
ing. Mr.
Lee's Pa-
tent.

Manufactures.

originally proposed, were screwed into that side of the bearer furthest from the workman. The corresponding breakers were fixed upon another heavy piece of timber, supported by two side timbers very nearly fitting between the upright standards and extending to near their tops, where these were fixed by two screw bolts or round rod of iron passing through the whole four, and serving as a hinge upon which this last apparatus might swing like the batten and swords of a weaver's loom, and to be worked in the same way by a cross bar or handle, near the bottom of which the left hand was to be applied. The flax having passed the first machine was now to be held by the right hand, permitting it to hang down over the breakers and bearer, while the second set of breakers were to be forcibly drawn against it by the other hand; and by a continuance of this operation the fibre at length became freed from all the woody matter and bark, which fell to the ground, and when afterwards passed through a pair of finely fluted rollers was finished and ready for the hackle.

An entirely different process has been since invented and secured by Patent by Mr. Bundy, of Camden Town. For this purpose he employs two machines, a breaker and a rubber. The first of these is for the purpose of separating the harle from the boon as usual, but the process is different. The latter is intended for rubbing and separating the fibres so as to produce it in its greatest state of perfection, and for finally cleansing it before it is sent to the hackler.

Bundy's
Patent
breaking
machine.

(1001.) *Breaking machine.*—This consists of fluted or toothed cylinders, but it varies from other machines of the same kind used for this purpose by the inequality in the depth of the teeth, the play or space which is left between one tooth and another, and in the reciprocating motion of the cylinders combined with a progressive motion, instead of being progressive only, as in the usual practice. The simple manner in which this complex motion is produced displays great ingenuity.

Pl. lxx.
Fig. 3, 4.

This machine is represented in plate lxx. fig. 3, 4; the former is a side view. The framing A in this particular machine is timber, (but it may, of course, be formed of iron.) This serves to support the five breaking cylinders C, C', D, E, E, turning on pivots; C, D, and C' move in brass bearings fixed upon the boards or support B on the two opposite sides of the machine, while E, E merely lie above and between C, D, D, C', and are drawn down to these by two rods, as seen at F, F'; the lower ends of these are joined by a rod or connecting bar, while another rod proceeds downwards, its lower end being fixed by a lower adjusting nut G, near the pin or fulcrum H of the lever or presser H I, which is loaded with a weight J. There is a similar lever on each side of the machine to bear down the four ends or pivots of the two rollers E, E, and the ends of these levers nearest to I are united with a cross bar, by means of which one weight J acts on them both, and is made to press equally by an adjusting nut and screw on each side, like G. K L is a lever placed under the machine, one end of which is attached to the weight J in such manner that, by pressing down its end L, J is raised, and all pressure is instantly prevented between the superior cylinders E, E, and those under them at C, D, C', for stopping the operation of the machine at any time. The breaking cylinders are about 18 or 20 inches in length, and are made of beech or any hard wood, and are all similar to each other in dimensions, and in having breakers, which act also as teeth, extending like projecting plates

their whole length parallel to the axis. These breakers or teeth are formed of thin hoop iron, let about half its width into saw cuts in the cylinders, into which they are driven, and they are retained in their places by iron hoops put on to each end of the cylinders: they are about half an inch asunder, their external edges are well rounded, so as not to cut the flax, and they are alternately long and short, the long or deep teeth projecting about three-quarters of an inch from the cylinder, while the short ones are about half that length. In placing the lower breaking cylinders in their places, care must be taken that they do not touch each other, since their teeth are only to connect through the medium of the two upper rollers which press them. The axis of the roller D is longer than the others, and extends on both sides beyond the frame, and upon each end of it is fixed a cast-iron wheel, by which motion is to be given to the cylinder, and through this to all the others. Both the wheels are of the same diameter, but one is a ratchet wheel, as will be seen in the last figure, while that on the opposite side is a spur or common toothed wheel, as will be seen in fig. 4, which represents such parts of the machine on the opposite side as are essential to its motion, and the same letters of reference are used in both figures to denote similar parts.

The first motion is given to this machine from the iron spindle O, fig. 3, which may be turned by a handle, or by a band and rigger, as at P; it may also be connected with a pair of spur wheels and a fly, as shown in the same figure, to assist its motion. On each end of the lower spindle, if two are used, there is a crank, as at Q, attached to a connecting rod V, the opposite end of which, in fig. 4, is attached to a pall or lever turning on a centre S, so when O or O' is turned, the end of this lever will describe a portion of a circle, shown by the dotted line T A, and will engage with the ratchet teeth of the wheel M, and carry it partly round; while on the other side of the machine, shown in fig. 4, the connecting rod V passes from the crank of O to a toothed segment U, the teeth of which work into the teeth of the upper spur wheel N, fixed upon the opposite gudgeon of the breaking cylinder D. The connecting rod on this side of the machine must be so adjusted in length that in its motion outwards the end tooth of U next to it must be withdrawn out of the teeth of the wheel N, but that when it moves in a contrary direction, or from T towards A, it must move completely in the teeth of the wheel, and not leave them, and of course N at this time is incapable of any other motion but what the segment U also has.

The connecting rod Q V, in fig. 3, must also be so adjusted in length to the pall or gathering tooth S as to make it continue to act upon its wheel M, for the space of one tooth of N, in fig. 4, after the segment U has been withdrawn from its wheel N; and thus, although the motion of U would produce a backward and forward motion of its corresponding wheel N, and the breaking cylinder D, and consequently of all the other cylinders, yet by the after action of S upon M, the roller D and its wheel N are made to advance gradually by the space of one tooth of N for every revolution of O; and thus a slow but regular progressive motion of the cylinders is obtained, at the same time that the vibratory or oscillating motion is going on. The flax is fed or supplied by placing it in handfulls on the feeding trough Z, and pressing it gently between the rollers C' and E, and it is delivered out from between the rollers E and C', at the

Mechanical
Processes.

Manufactures.

Bundy's
rubbing
machine.
Fig. 5.

end of the machine next to L, in a sufficiently clean and divided state to enter the rubbing machine, which will be next described. The superiority of this machine over common fluted rollers needs no comment; since the distance between the teeth and the shake, which is produced by the alternating motion of the cylinders, exactly gives that action which is best suited to break off and disengage the bark and woody matter, which, when dry, is quite brittle, and falls to the bottom of the machine. Once passing the rollers is in general sufficient for either flax or hemp stalks, but the work is rendered more perfect by a second passage through them, which does not at all injure the fibre.

(1002.) *Rubbing machine.*—This is used immediately after the preceding breaking process. Fig. 5 represents a section of the machine, in which *a* is the wooden frame for supporting the other parts of the machinery, *b* the bearers for the three rollers *c, d, e*, disposed as in the breaking machine; but in this case they are only for the purpose of drawing or leading the flax through the machine; (the breaking being presumed to have been already done by the last described, or any other process;) they must be fluted or grooved, or may be made in the same manner as the breaking cylinders, but with the teeth of equal length, much shorter, and of a finer gauge or pitch; *f* is a rigger or pulley, to which a rapid circular motion is to be given; it is hung on a shaft or spindle turning in brass bearings, and fixed to the frame *a*; on the end *h* of this spindle is formed an endless screw or worm, which turns a small wheel *i*, fixed upon the lower end of an iron spindle *k* turning in bearings, and leading, by a bevel pinion at its upper end, to the face wheel *n*, which is fixed on to one of the gudgeons of the fluted or toothed roller *e*, so that whenever the rigger *f* is turned, even with a rapid motion, a very slow motion will be communicated to the rollers *c, d, e*. The most essential part of this machine consists of the rubber boards *o, p, q, &c.*, which are placed at the front of the machine; these are seven in number in the figure, but may be more or less, and are about an inch in thickness; they may be made of beech, oak, or any moderately hard wood. Their edges or sections can only be seen in this representation, but their length may be from eight inches to a foot or more. The board *o* is firmly fixed to the top of the framing *a*, and is without motion, while those marked *p, p, p* are supported upon the two strong cylindrical iron pins *s*, which are firmly screwed into the frame *a*, and pass through holes which fit them in the boards *p, p, p*, so that these last can be moved to a greater or less distance from each other, but are incapable of up-and-down motion. The intermediate boards *q, q, q* are so much shorter as to pass between the iron pins *s*, and admit of an up-and-down motion; for this purpose they are all connected together by an iron link or staple *x*, fixed upon the top of the connecting rod *u*, the lower end of which works upon a crank in the middle of the first spindle upon which the rigger *f* is placed, so that, in every revolution of *f*, the movable boards *q, q, q* are driven upwards and downwards between the more stationary boards *p, p, p*, and the one which is fixed at *o*. The whole of the boards are drawn towards *o* by means of a rod on each of their sides passing through *q, q, q* and *o*, and acted upon at *t* by weights or spiral wire springs, and the whole of the boards are perforated with a slit or mouth from four to six inches long, (according to their width,) and about a quarter of an inch

wide, placed near their tops at an equal distance from the top of each, and nicely rounded off on all its edges. The consequence will be that whenever the crank is in a horizontal situation, all these slits will coincide; but when the crank is down, as in the figure, the slits *q, q, q* (which slits are seen only in section) will be below those in *p, p, p* and *o*, while when the crank is up they will be elevated above them; and thus it will easily be perceived that if the flax, or any other flexible material, is passed through the slits in the boards when they do coincide, and then conducted between the toothed rollers, that while these draw it slowly on through the machine, the boards *p, p, q, q, &c.*, by their rapid up-and-down motion, will effectually rub it and cleanse it from any extraneous matter which may adhere to it, as well as open the fibres. And for the better regulation of this operation, *v* is a treadle or lever near the foot of the attendant, by pressing on which the weight *w*, which depresses the top roller *d*, will be raised, in consequence of which the rollers will cease to draw, although the rubbing still continues, so that its velocity in passing the machine may be correctly regulated at the will of the superintendent.

For the purpose of setting this machine to work in the first instance, and charging it with flax, the tops of all the rubbing boards are movable, and made to separate through the slits which are made in them; for which purpose they are attached at one end by strong hinges, and are fixed down at the other by the thumb screws which are shown in the figure, or by any other sufficient fastenings. It will, however, only be necessary to open them on first setting them to work, since all future qualities of flax to be rubbed may be tailed on that which is already in the machine. The flax is to be supplied by placing it on a perpetually revolving cloth, or feeding table, joined to the end *s* of the machine, and worked by connection with some of its wheels; but this is not shown in the figure, as it forms no part of the invention, and is common in all cotton and flax manufactories.

The average crop which has been produced in England from sowing three bushels of flax or lintseed on an acre of land, is two and a half tons of flax stem, which, when broken and prepared, yields from ten to thirteen hundred weight of harle or flax fit for hackling; and the boon or woody matter which falls through the machine will yield from ninety to a hundred bushels of chaff from the seed, and fit provender for horses or cattle; and from thirty-five to forty hundred weight of chaff from the stem, making a valuable manure, while from ten to fourteen bushels of seed may, in almost all cases, be procured from the same quantity.

(1003.) *Hackling.*—This is the next operation in the preparation of the flax, and resembles in some measure the combing in the woollen and worsted manufactures, the object of it being to straighten the fibres and to lay them parallel to each other. The hackle is shown in fig. 6, 7, plate lxx. It consists of many teeth fixed in a plain, flat board, as seen at A and B. When used, it is firmly fixed to a bench before the workman, who stretches the flax upon the teeth of the hackle drawing it also quickly through them. To persons unacquainted with this kind of work, this has the appearance of a very simple operation which it indeed is, but still it requires a good deal of practice to become expert at it so as to produce a level and fine fleece and without wasting the good material. Our figures only represent one hackle,

Mechanical
Processes.

Hackling
process.

Fig. 6, 7.

Manufac-
tures—
Spinning
flax.

but the workman uses several different ones, of various degrees of fineness, according to the quality of the material on which he is operating.

(1004.) *Spinning flax.*—Till late years flax was spun in single threads by a wheel and spindle, but the improvements which have been since introduced into the cotton trade have been extended also to flax; and in a general view of the case the operations are not very different, although, from the strength and length of the fibre of flax, there is a considerable difference in the degree of draught and power in the several parts of the machinery. One of the finest flax manufactories in the Kingdom is that of Messrs. Marshall and Co., of Leeds, in Yorkshire, and the following is a short description of it, written after being favoured with an inspection of it. The building consists of five floors, and the operators, of which there are some hundreds, are principally girls from ten to twenty years of age. The propelling powers are two seventy-horse steam-engines, one on each side of the building. Each of these drives a series of vertical shafts acting on one shaft, (by means of couplings,) which passes through all the floors; and on each floor there are bevelled wheels on this main shaft which drive various others, lying in a horizontal direction, some of them extending in length to one hundred and thirty feet. From these, and drums upon them supplied with proper straps, all the machinery on each floor is driven, every strap having a fast and loose pulley for putting the machine in and out of gear.

The flax is delivered at the mill, from the grower, in the state we have described, being whole, freed from all its woody particles. In this state it is conveyed from the wagons in which it is brought, by a lifting apparatus, like that of a flour-mill, to the upper floor of the building, where it is opened, and where the process of spinning, or rather the preparation for spinning, commences.

The flax, in this state, is from 26 to 30 or 36 inches in length, and the first step is to take a quantity of it and divide it into three lengths; the part nearest to the root being coarse and strong, the middle part fine and strong, and the upper part still finer, but not so strong. Thus each length being divided into three, and all those of the parts from the bottom, middle, and top being collected into separate heaps, three distinct qualities of thread are to be formed.

The separation of these first lengths into three is effected by a very ingenious machine, consisting of a number of vertical wheels and a centre wheel, furnished with a kind of teeth. The length of flax is held transversely against these wheels, and is passed between two one on either side, while the centre wheel tears it across by separating but not cutting the fibres. This cuts off the bottom part of the length of flax; the remaining part is then submitted to the same process and the middle part cut from the top, each sort being collected in one heap, so as to effect a separation of the three qualities above named. Each division, from what has been before seen, will be, of course, about ten or twelve inches in length. In the next stage, these lengths are fixed in a sort of vice at one end, spread out to a breadth of six or seven inches; several of these are fixed on a sort of revolving drum, at distances of about a foot from

each other, their unsupported ends falling on an internal drum covered with strong cards, the internal drum revolving one way with considerable velocity, and the external in the opposite direction rather slowly, and thereby the lengths of flax are rendered very smooth and straight; they are then dexterously removed by an attendant, generally a girl, and placed with their other side downwards in the next machine and again removed. It should be remarked that these only pass over the upper part of the internal drum; for it is obvious if they passed below, their weight would cause them to fall from, and not upon, the carding roller.

These several operations being performed, the next step is to place these pieces of flax, one just reaching the other, on a feeding cloth, and by the hand slightly to combine their ends: the first end is then passed between two card rollers, or rollers furnished with teeth, which carry the whole forward, while the extreme end passes between two rollers of iron, the latter moving with considerably greater velocity than the former, in some cases 30 to 1, and consequently the flax is now lengthened 30 to 1, and its thickness reduced accordingly. In passing from the roller the flax receives no twist, but comes out flat, and of about the breadth of narrow tape, and is caught in a cylindrical tin can placed below to receive it; when a certain length has been received sufficient to fill the can, a bell rings, an attendant breaks the flax, removes the can, and places another. The flax in the full can is then taken to another machine, where it is again lengthened, and so on to different degrees, according to its intended fineness. After it is properly reduced in the flat state above described, it receives in its last stage a very slight twist so as to reduce it to a round thread. It is then received on bobbins, and is in a proper state for spinning; the process of which differs only in degree from that already described under the article COTTON MANUFACTURE.

In the process above described, where the flax passes over the revolving cylinder, a part of the shorter fibres are detached from the general mass; and this is more particularly the case with the upper part or division of the original length. This is collected and submitted to the operation of carding, similar to the carding of cotton, and in all its subsequent processes is treated in very nearly the same way; this produces a fine but not very strong thread.

(1005.) The linen trade, though not increasing at the same rapid rate which marks the progress of the cotton manufacture, is still in a healthy state, and is stated by Mr. Marshall to have been doubled in England and trebled in Scotland within the last forty-five or fifty years; and the improvements in its machinery have been such that the same gentleman states, in his examination before the Select Committee on Manufactures, that he has, in order to keep pace with them, reconstructed his mill twice within the same period. This must have incurred no inconsiderable expense, seeing that the number of the hands employed in the mill at present amounts to 1229 adults and children.

The following Tables will show the amount of the imports and exports of flax, hemp, and manufactured linen cloth and canvass within the several periods stated in them.

Mechanical
Processes.

State of the
linen trade

Manufac-
tures.

An Account of the Number of Yards of British and Irish Linen, and the Number of Ells of British and Irish Sailcloth, exported from the United Kingdom, in each Year, from 1820 to 1831, both inclusive.

Years.	British Linen.	Irish Linen.
	Yards.	Yards.
1820	24,066,914	12,455,419
1821	28,199,765	15,408,561
1822	33,762,229	15,931,939
1823	34,624,512	16,765,928
1824	43,879,893	17,933,195
1825	33,643,655	16,023,268
1826	23,619,428	10,868,407
1827	38,280,766	14,022,496
1828	44,555,341	11,924,603
1829	43,499,268	11,924,918
1830	46,232,243	13,244,269
1831	50,799,723	14,738,358

Years.	British Sailcloth.	Irish Sailcloth.
	Ells.	Ells.
1820	1,226,335	18,117
1821	1,339,164	12,153
1822	1,259,919	16,039
1823	1,206,715	32,239
1824	1,593,291	66,185
1825	1,879,506	51,104
1826	4,343,924	55,178
1827	2,211,529	52,413
1828	2,962,393	83,903
1829	1,768,093	51,256
1830	1,922,211	32,550
1831	2,928,464	28,185

An Account of the Quantities of Irish Linen imported into the United Kingdom, and the Quantities retained for Home Consumption, in each Year, from 1820 to 1825, both inclusive.

Years.	Imported.	Retained for Consumption.
	Yards.	Yards.
1820	42,665,928	33,243,497
1821	45,518,719	33,888,618
1822	43,226,710	30,372,703
1823	48,066,591	34,171,905
1824	46,466,950	31,292,598
1825	52,560,926	38,755,733

An Account of the Quantity of Flax and Tow imported into and exported from the United Kingdom, and the Quantities entered for Home Consumption.

Years.	Importation.	Exportation.	Consumption.
	Cwts.	Cwts.	Cwts.
1820	382,389	17,866	376,170
1821	498,554	8,773	491,582
1822	610,106	7,282	607,540
1823	553,937	9,719	553,599
1824	742,531	11,677	739,651
1825	1,055,233	7,571	1,018,837
1826	688,622	8,956	697,488
1827	907,079	6,331	896,889
1828	876,189	6,899	882,289
1829	922,040	8,580	909,709
1830	944,096	3,633	955,112
1831	936,411	10,548	918,883

An Account of the Quantities of Undressed Hemp imported into and exported from the United Kingdom, and the Quantities entered for Home Consumption.

Years.	Importation.	Exportation.	Consumption.
	Cwts.	Cwts.	Cwts.
1820	426,163	13,992	398,005
1821	255,798	24,090	341,547
1822	616,454	9,157	507,577
1823	667,141	7,417	632,904
1824	571,936	8,011	588,917
1825	595,089	3,129	644,054
1826	489,330	2,064	509,059
1827	573,393	21,013	508,545
1828	504,120	18,476	460,544
1829	374,933	13,181	422,122
1830	506,771	9,587	400,959
1831	530,820	29,236	504,308

Manufac-
tures.

An Account of the Quantities of Foreign Linens imported into the United Kingdom, in each Year, from 1820 to 1831, both inclusive.

Mechanical
Processes.

Years.	Cambrics and French Lawns.	Lawns not French.	Damask and Diaper Tabling, Towelling, and Napkinning.		Drilling and Pack Duck.	Sail-cloth.	Sails.	Hessen Spruce and Packing Canvass, and Plain Linen of Germany, Silesia, Russia, and the Netherlands.		
	Pieces.	Pieces.	Square Yards.	Yards.	Ells.	Ells.	Value. £. s. d.	Ells.		
1820	43,534	...	16,148	11,801	84	571	1,961 0 6	130,785		
1821	29,766	...	5,909	2,704	1,398	707	1,517 0 0	134,748		
1822	34,051	...	14,906	12,873	22	577	1,601 0 0	116,360		
1823	31,913	2	8,795	6,036	3,554	131	956 4 8	183,172		
1824	30,496	...	5,429	3,201	11,903	198	1,128 1 5	130,109		
1825	40,354	146	23,156	22,779	3,001	183	1,413 12 8	253,669		
Years.	Cambrics and Bordered Handkerchiefs.	Lawns not French.	Damask and Damask Diaper.		Drillings Ticks, and Twilled Linen.	Sailcloth.	Sails.	Plain Linen and Diaper.		
	Pieces.	Square Yards.	Square Yards.		Square Yards.	Square Yards.	Value. £. s. d.	Entered by the Sq. Yd.	Entered by the Ell.	Entered by the Piece.
1826	30,828	...	51,972		67	4,172	1,759 10 4	1,524	1,217,604	1,150
1827	62,095	742	5,206		3,618	33,114	2,515 17 7	30,442	688,504	3,351
1828	50,402	21	8,327		8,011	7,629	2,443 16 8	131,226	706,490	10,432
1829	40,778	602	5,411		11,639	11,663	425 8 1	138,458	372,697	31,638
1830	54,357	...	9,544		236	18,863	460 16 10	94,992	240,700	29,326
1831	55,092	572	8,126		2,810	38,534	452 9 7	28,190	425,824	17,102

An Account of the Quantities of Foreign Linens exported from the United Kingdom, in each Year, from 1820 to 1831, both inclusive.

Years.	Cambrics and French Lawns.	Lawns not French.	Damask and Diaper Tabling, Towelling, and Napkinning.		Drilling and Pack Duck.	Sail-cloth.	Sails.	Hessen Spruce and Packing Canvass, and Plain Linen of Germany, Silesia, Russia, and the Netherlands.		
	Pieces.	Pieces.	Square Yards.	Yards.	Ells.	Ells.	Value. £. s. d.	Ells.		
1820	772	...	84	413	369	...	...	39,147		
1821	615	...	40	37	...	...	...	6,116		
1822	875	4	246	94	...	...	...	6,820		
1823	869	...	133	406	...	90	...	34,298		
1824	648	8	345	...	221	...	22 0 0	41,302		
1825	603	...	55	57	...	...	102 4 7	26,725		
Years.	Cambrics and Bordered Handkerchiefs.	Lawns not French.	Damask and Damask Diaper.		Drillings, Ticks, and Twilled Linen.	Sailcloth.	Sails.	Plain Linen and Diaper.		
	Pieces.	Pieces.	Square Yards.		Ells.	Square Yards.	Value. £. s. d.	Entered by the Sq. Yd.	Entered by the Ell.	Entered by the Piece.
1826	878	75	481		60	...	...	19,659	545,146	500
1827	754	...	952		80	9,467	...	28,168	300,374	4,028
1828	994	21	539		6,157	27,469	...	152,065	723,857	9,144
1829	659	603	446		19,371	7,068	...	124,200	451,533	30,175
1830	424	...	447		425	21,639	...	138,142	249,991	20,793
1831	507	572	421		1,718	20,069	...	78,760	454,431	18,956

Manufactures.

An Account of the Quantities of Foreign Linen retained for Home Consumption in the United Kingdom, in each Year, from 1820 to 1831, both inclusive.

Mechanical Processes.

Years.	Cambrics and French Lawns.	Lawns not French.	Damask and Diaper Tabling, Towelling, and Napkining.		Drilling and Pack Duck.	Sail-cloth.	Sails.	Hessen Spruce and Packing Canvass, and Plain Linen of Germany, Silesia, Russia, and the Netherlands.
	Pieces.	Pieces.	Square Yards.	Yards.	Ells.	Ells.	Value. £. s. d.	Ells.
1820	40,297	...	15,459	11,777	2,142	571	2,031 6 5	186,090
1821	31,066	...	6,079	2,680	115	707	1,543 10 0	176,713
1822	33,367	...	11,005	12,129	22	577	1,601 0 10	140,884
1823	31,186	2	12,437	6,110	3,554	131	956 4 8	134,168
1824	29,447	5	5,372	3,404	7,418	198	1,106 1 5	193,623
1825	37,413	6	15,225	21,183	4,327	183	1,311 8 1	125,439
Years.	Cambrics and Bordered Handkerchiefs.	Lawns not French.	Damask and Damask Diaper.		Drillings, Ticks, and Twilled Linens.	Sail-cloth.	Sails.	Plain Linen and Diaper.
	Pieces.	Square Yards.	Square Yards.		Square Yards.	Square Yards.	Value. £. s. d.	Entered by the Square Yard.
1826	32,764	106	1,772		12	121	1,759 10 4	1,235
1827	60,407	742	3,010		2,069	526	2,515 17 7	2,442
1828	49,864	...	4,245		2,064	78	2,443 16 8	1,817
1829	41,224	...	8,345		955	81	425 8 1	692
1830	53,787	...	8,285		236	213	460 16 10	203
1831	53,971	...	10,371		...	7400	452 9 7	140

Silk Manufacture.

Early history.

(1006.) The manufacture of silk is generally supposed to commence from that state in which it is received in this Country till it is converted into an article of dress. We are, however, rather disposed to enter upon the business at an early stage, and to trace, as we have done in our other manufacturing articles, the several processes from the first raw state of the material. This seems to be the more necessary here, as it has been for several years a favourite notion with many persons that the silkworm might be introduced into this Country or into Ireland with great advantage.

Silk very scarce with the Romans.

The art of converting the web of the silkworm into articles of dress is of ancient date, the discovery having been attributed to Pamphila, the daughter of Platis. Silk was a very scarce commodity amongst the Romans, having been sold by them weight for weight with gold; and even in the time of Aurelian, in the year 275, it was so expensive that he is said to have refused his Empress a particular request for a silk dress, on account of the price being so great. It was, however, known in Rome as early as the time of Tiberius. At a later date, it is said that immense sums were sent out of the Roman Empire to the further parts of the then known world, for the purchase of a foreign manufacture which employed no citizen or tributary subject; and a great part of the profits arising from so lucrative a commerce fell into the hands of the Persians, the inveterate enemies of Constantinople. In whatever manner, indeed, the traffic had been carried on, so copious an importation of so expensive an article from

so vast a distance must have tended to impoverish the Empire. The Emperor Justinian had long desired to turn this lucrative commerce into a Roman channel, but insuperable obstacles prevented the execution of his design. Those difficulties, however, which all the policy of the Emperor could not remove, were surmounted by the enterprising sagacity of two Monks, who, in the quality of missionaries, had long resided in China. Amidst their religious occupations, they had viewed, with an investigating eye, the manufacture of silk in that Country, the myriads of silkworms, and the mode of their treatment. They discovered that the importation of so delicate and short-lived an insect from so great a distance was impracticable; but they imagined that in the eggs a numerous progeny might be preserved and propagated. Knowing how agreeable the undertaking would be to the Imperial Court at Constantinople, they arrived, after a long journey, at that metropolis of the Roman Empire; and having imparted their project to the Emperor, were, by the liberality of his gifts and the splendour of his promises, encouraged to carry it into execution.

The two Monks having travelled back to China, and by concealing the eggs of the silkworm in a hollow cane, deceived a people, ever jealous of its commerce, returned in triumph to Constantinople with the spoils of the East, having made a greater conquest than either Justinian or his celebrated General Belisarius had ever achieved. Under their directions, the eggs were hatched by artificial heat; the worms were fed by leaves of the mulberry tree; they lived and laboured, and, by the use of proper means, the race was propagated and multi-

Silkworms first brought from China to Constantinople.

Manufac-
tures.

plied. Experience and reflection soon correct the errors incidental to a novel attempt, and in a short time the subjects of Justinian equalled the Chinese in the management of silkworms. From Constantinople this valuable insect has been gradually introduced into all the Southern parts of Europe, and the material produced by it is now manufactured in almost every Country in that quarter of the globe. Thus, in consequence of a singular circumstance in the history of commerce, of which the epoch is assigned to A. D. 552, modern Europe enjoys, at an easy expense, one of the most costly luxuries of the Ancients, which was formerly peculiar to China, and once sold at Rome "*for its weight in gold.*"

Introduc-
tion into
Sicily,
France, &c.

About 1130, Roger II., King of Sicily, established a silk manufacture at Palermo, and another in Calabria, managed by workmen taken as slaves from Athens, Corinth, &c., of which that Prince made a conquest in his expedition to the Holy Land. By degrees the rest of Italy and Spain learned from the Sicilians and Calabrians the management of the silkworm and the working of the silk; subsequently, it was carried into France, about the reign of Francis I.

Broad silk
manufac-
ture in Eng-
land.

We have stated, in our history of the hosiery trade, that silk was first known in England, in a knitted form for stockings, in the reign of Henry VIII., but as early as the reign of Henry VI. silk was used in a woven form as an article of dress; it was also in some measure manufactured at that time in this Country, Henry having silk women, who were, however, probably only employed in needlework of silk. Henry VIII. wore the first pair of silk stockings in England, and in the latter years of the reign of Elizabeth silk stockings were her only wear. Towards the latter end of the reign of James I., *i. e.* about 1620, the broad silk manufacture was introduced into this Country, and proceeded with great vigour and advantage; in 1629, the silk manufacture was become so common in London that the silk throwsters of the city and parts adjacent were incorporated under the name of Master, Wardens, &c., of the Silk Throwsters, and in 1661 this Company employed above forty thousand persons. The revocation of the Edict of Nantes, in 1685, gave another stimulus to the English silk manufacture, by that measure forcing over as emigrants to this Country many of the most ingenious workmen in the trade.

Invention
of the silk-
throwing
mill.

In 1719, a silk-throwing mill was erected at Derby, and from that time to the beginning of the present century various improvements were introduced; but those made since that time, or during, perhaps, the last fifty years, have been very great, and the silk manufacture of this Country is now in a very high state.

The following account of the first silk mill erected in England will be interesting. At the commencement of the last century, a person of the name of Crochet erected a small mill near the present works, with the intention of introducing the Italian method of spinning into this Country. About 1715, a similar plan was in the contemplation of a mechanic and draughtsman named John Lombe, who travelled into Italy to procure drawings and models of the machines necessary for the undertaking. After remaining some time in that Country, and gaining as much information as the jealousy and precautions of the merchants of Italy would allow, he returned with two natives, accustomed to the manufacture, into this Country, and fixed upon Derby as a proper place to establish his works. He

VOL. VIII.

Mechanical
Processes.

agreed with the Corporation for an island, or rather swamp, in the river, 500 feet long and 52 wide, at the rent of about £8 yearly. Here he established his silk mills, and in 1718 procured a Patent to enable him to secure the profits for fourteen years. But Lombe did not live much longer; for the Italians, exasperated at the injury done to their trade by its introduction into England, sent an artful woman over, who associated with the parties in the character of a friend, and, having gained over one of the natives who had originally accompanied Mr. Lombe, administered a poison to him, of which, it is said, he ultimately died. His death, however, did not prove fatal to his scheme; for his brother, and afterwards his cousin, carried on the business with energy, and employed more than three hundred persons. A little before the expiration of the Patent, Sir Thomas Lombe petitioned for a renewal of it; but this was refused, and instead of it, £14,000 was granted him, on condition that he should allow a complete model of the works to be taken; this was accordingly done, and afterwards deposited in the town for public inspection. The property now wholly belongs to the Corporation: the present occupier employs about two hundred and forty hands.

This extensive mill stands upon a huge pile of oak, double planked and covered with stonework, on which are turned thirteen stone arches which sustain the walls. Its length is 110 feet, its breadth 39, and its height 55 feet; it contains five stories: in the three upper ones are the Italian winding engines, which are placed in a regular manner across the apartments, and furnished with many thousand swifts and spindles, and engines for working them. In the lower two rooms are the spinning and twist mills, all of which are of a circular form, and are turned by upright shafts passing through their centres, and communicating with shafts from the water wheel. The spinning mills are eight in number, and give motion to upwards of 25,000 reel bobbins, and nearly 3000 star wheels belonging to the reels. Each of the four twist mills contains four rounds of spindles, about 389 of which are connected with each mill, as well as the numerous reels, bobbins, star wheels, &c. The whole of this elaborate machine, though distributed through so many apartments, is put in motion by a single water wheel twenty-three feet in diameter, situated on the West side of the building.

All the operations, from winding the raw silk to organzining or preparing it for the weavers, are performed here; the raw silk is chiefly brought in skeins or hanks from Piedmont or China. The skein is first placed on a hexagonal wheel or swift, and the filaments which compose it are regularly wound off upon a small cylindrical block of wood or bobbin. To wind a single skein is the work of five or six days, though the machine be kept in motion for ten hours daily, so astonishingly fine are the filaments of which it is formed; the silk thus wound upon the bobbins is afterwards twisted by other parts of the machinery, and is then sent to the doublers, who unite four, seven, or ten threads into one, according to the uses for which it is designed, the fine kind going to the stocking weavers, and the others to different manufacturers.

Till within a few years it was thought that the silk manufactures of this Country stood in need of protection against the French silks, the importation of which was prohibited, but our own manufacturers paid a duty on the raw silk imported. The removal of these restric-

Manufac-
tures.

tions, or at least the modification of them, led to much interesting inquiry and discussion in the British Parliament, but was at length effected; and the result has been, that the quantity of raw silk imported and manufactured in this Country, in the first ten years subsequent to this Act, has been more than double that which it was in the ten preceding years, a triumphant argument in favour of the freedom of trade. This will be seen by the following statement.

Quantities of Raw Silk imported
from 1814 to 1823.

lbs.	
1814	2,119,974
1815	1,475,389
1816	1,088,334
1817	1,686,659
1818	1,922,987
1819	1,848,553
1820	2,027,635
1821	2,329,808
1822	2,441,563
1823	2,468,121

Total 19,409,023

Quantities of Raw Silk imported
from 1824 to 1833.

lbs.	
1824	4,011,048
1825	3,604,058
1826	2,253,513
1827	4,213,153
1828	4,547,812
1829	2,892,201
1830	4,693,517
1831	4,312,330
1832	4,373,247
1833	4,684,499

Total 39,585,378

Mechanical
Processes.

Quantity of
raw silk
imported
from 1814
to 1833.

Revenue Returns, showing the Quantities of Raw and Manufactured Silks imported from different Countries into Great Britain, and the Amount of Manufactured Silk Articles exported, &c., from 1820 to 1831, inclusive.

Revenue
Returns of
exports and
imports.

RAW SILK IMPORTED.									
Years.	India.	Cape.	China.	Turkey.	Italy.	France.	Other Countries.	Total.	
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1820	1,127,884	...	221,515	217,147	170,139	393,753	85,253	2,215,691	
1821	1,106,659	...	218,921	176,578	236,451	332,170	48,965	2,119,744	
1822	924,223	...	172,679	318,344	202,127	364,668	78,251	2,060,292	
1823	1,322,208	...	287,607	203,844	197,038	397,919	44,550	2,453,166	
1824	1,105,170	...	202,130	319,063	338,431	1,047,641	39,544	3,051,979	
1825	897,582	6,929	123,107	341,107	562,735	799,181	125,151	2,855,792	
1826	1,620,269	13,179	169,591	240,840	154,203	266,662	23,076	2,487,820	
1827	1,122,393	11,095	128,234	358,757	287,332	1,133,206	105,909	3,146,926	
1828	1,213,733	20,964	212,895	671,392	578,497	1,389,675	169,267	4,256,423	
1829	2,116,596	13,447	120,970	281,421	227,899	787,826	86,595	3,594,754	
1830	1,736,231	...	19,198	464,203	273,414	860,961	86,631	3,440,638	
1831	1,725,650	26,930	8,374	451,421	115,766	821,349	86,375	3,235,865	
WASTE AND KNUBBS.									
1820	78,838	...	5	...	10,256	3,440	...	92,539	
1821	...	...	9	...	53,312	24,659	3,317	81,297	
1822	...	...	...	...	85,197	19,836	12,448	117,481	
1823	9,542	...	...	...	43,647	5,173	636	58,998	
1824	...	...	...	...	40,276	40,477	2,911	83,664	
1825	8,653	...	...	...	165,524	86,153	1,114	261,449	
1826	...	...	...	...	...	...	...	...	
1827	...	...	...	...	...	...	...	...	
1828	...	...	...	...	...	...	...	...	
1829	...	...	...	...	...	...	...	...	
1830	...	...	...	...	200,880	246,296	16,527	463,703	
1831	...	...	...	...	410,750	329,235	16,743	756,728	
THROWN SILK.					TOTAL FROM THE THREE PRECEDING TABLES.				
Years.	Italy.	France.	Other Countries.	Total.	Years.	Raw Silk.	Waste.	Thrown.	Total lbs.
1820	333,513	...	123	333,636	1820	2,215,691	92,539	333,636	2,641,866
1821	341,152	2	...	341,154	1821	2,119,744	81,297	341,154	2,542,195
1822	502,784	3	8	502,975	1822	2,060,292	117,481	502,975	2,680,568
1823	368,468	1	1	368,470	1823	2,453,166	58,998	368,470	2,880,634
1824	341,587	416	2	342,005	1824	3,051,979	83,664	342,005	3,477,648
1825	608,292	168,241	996	777,529	1825	2,855,792	261,449	777,529	3,894,770
1826	12,023	164,152	1,230	177,405	1826	2,487,820	...	177,405	2,665,225
1827	8,541	443,208	12,052	463,801	1827	3,146,926	...	463,801	3,610,727
1828	7,132	454,086	47,600	508,818	1828	4,256,423	...	508,818	4,765,241
1829	3,765	188,233	19,181	211,179	1829	3,594,754	...	211,179	3,805,933
1830	1,485	370,575	41,780	413,840	1830	3,440,638	463,703	413,840	4,318,181
1831	698	612,590	15,993	629,281	1831	3,235,865	756,728	629,281	4,621,874

Manufac-
tures.Declared Value of all Kinds of British Goods
exported.Mechanical
Processes.

INDIAN MANUFACTURE.										MANUFACTURES OF EUROPE.																	
Years.	Silk Handkerchiefs.		Silks and Crape.		Crape, Shawls, and Gown.		Silk or Satin.		Ribands.	Gauze.		Gauze Ribands.		Crape.	Velvet.	Velvet Riband.	Velvet Riband embossed.	Fancy Silk Net.	Silk and Metal.	Ribands, Silk and Metal.	Total entered by weight.	Lace and Net.	Turban, Caps.	Hats, Bonnets.	Millinery Dresses.	Various manufactured Silk Goods.	Value.
	Pieces.	No.	Pieces.	No.	Pieces.	No.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	Sq. Yards.	No.	No.	No.	No.	lbs.	£.
1826	208,066	32,754	77,776	20,228	7,682	5,282	3,618	5,496	5,518	52	52	28	339	54	48,301	40,676	106	119	44	44	21,489						
1827	55,183	18,150	24,200	38,549	20,958	6,504	16,211	16,381	15,404	242	242	223	583	220	115,278	122,238	326	428	213	50	54,128						
1828	69,628	15,577	4,789	61,323	35,517	4,600	21,917	24,951	18,470	2,101	317	11	512	125	169,530	171,005	295	414	275	13	77,189						
1829	67,465	10,164	1,959	64,612	35,517	20,052	21,917	22,786	13,743	317	3	3	438	412	121,953	109,729	383	528	330	30	85,259						
1830	77,953	2,978	17,620	51,417	20,958	30,241	16,211	28,884	14,847	529	42	223	583	220	126,370	114,381	368	535	298	154	44,923						
1831	101,023	3,796	16,157	82,400	20,958	33,488	21,917	19,669	12,264	345	95	223	583	220	148,729	54,164	199	412	200	27	35,722						

Years.	Goods all Silk.	Goods mixed of Silk and other Materials.	Total.
	£.	£.	£.
1820	203,666	168,109	371,755
1821	224,287	150,186	374,473
1822	215,898	165,805	381,703
1823	203,769	147,640	351,409
1824	183,635	258,961	442,596
1825	93,986	202,750	296,736
1826	73,247	95,554	168,801
1827	99,055	137,289	236,344
1828	97,346	158,524	255,870
1829	143,635	124,296	267,931
1830	355,790	165,220	521,010
1831	388,826	190,048	578,874

(1007.) *Silkworms*.—Having in the preceding columns given a sketch of the first introduction of silk into Europe, and into England in particular, and shown the immense extent of the silk trade in this Country, we shall proceed now to explain the several processes it has to undergo; but we ought in the first place to give a short description of the little worm which produces in so great abundance this valuable material, and the management of them as practised in those Countries of Europe most celebrated for the production of the raw silk.

The silkworm is an insect not more remarkable for the material it supplies, than for the many forms it assumes before and after its being enveloped in the cocoon or ball it weaves for itself. From a small egg about the size of a pin's head, which is its first state, it becomes a worm or caterpillar of a whitish colour inclining to a yellow. In this state its favourite food is the leaves of the mulberry tree, on which it generally subsists till it arrives at maturity; it then winds itself up in a silken bag or case about the size of a pigeon's egg, and becomes inside changed into an aurelia; in this state it remains without any signs of life or motion, but after some days, if not destroyed, it forces its way out and assumes the form of a moth or butterfly, and after providing for a re-creation by laying several eggs it dies, the eggs thus laid being brought again to life by the natural warmth of the next season, or by warmth artificially procured.

When the silkworm in its caterpillar state is arrived at the size and strength necessary for beginning its work, it makes its web, or that light tissue which is the beginning and ground of its admirable operation; this is the first day's employment; on the second it forms its folliculus or ball, and covers itself almost entirely over with silk; on the third it is quite hidden, and the succeeding days it thickens and strengthens its ball, always working from one single end, which it never breaks, and which is so fine and so long that those who have examined them attentively have found or stated the length of line in one ball to measure six English miles. In ten days the work is finished and the ball or cocoon is in its perfection; and when carried on in the open air, they have now to be taken down from the branches of the mulberry trees whereon the worms have hung them. This operation requires care and judg-

Manufac-
tures.

ment, for some worms working quicker than others, some are ready before others, and the forwardest, if left too long, would force their way out, which is best avoided.

This being done, the finest and strongest balls are preserved for breeding, and the rest are carefully wound. The winding is effected differently in different places, which will be described as we proceed. If there be no more than can be wound at once, the balls are laid for some time in an oven moderately hot, or they are otherwise exposed for several days successively to the greatest heat of the sun, in order to kill the insect, without which it would not fail to force its way out; and although it is not true, as is sometimes stated, that the silk is thus eaten away, yet the balls of this kind will not unwind so freely as those in which the insect is destroyed. The balls are of different colours, particularly those of different districts, but the most common are yellow, orange, a slight green, and flesh colour. We have spoken above of the worm fed in trees, but a large proportion of European raw silk is produced in chambers or sheds, either by parties employing certain amounts of capital and carrying on the business on a large scale, or by the peasants in their cottages. In these cases the worms are tended and fed by hand with leaves stripped from the mulberry tree, and they may thus be reared in Countries otherwise too cold for their production. It has been a favourite idea with many persons, ever since the time of James I., to introduce the silkworm into this Country or Ireland; James himself was a great advocate for making the attempt, and, indeed, it has been frequently made with some appearance of success. Recently, Mr. Murray, who had spent some time in Italy, and took particular notice of the management of the worm, has again called the attention of the nation to the subject, and has given a very interesting account of a Work by Count Dandolo, in which all the circumstances attending the treatment and produce of five ounces of ova are minutely traced. There are also statements respecting trials of different kinds of food, &c. We select the following particulars, which were given by the author in vol. ii. of the *Edinburgh Journal of Science*.

Management of Silkworms. Produce from Five Ounces of Ova.

1813. Days of Treatment.	Months.	Leaves and Stems.	Internal Tempe- rature.	External Tempe- rature.
First Age.	May.	lbs. oz.	Fahren- heit.	Fahren- heit.
1	18	*2 14	74° 75'†	64° 75'
2	19	4 0	74 75	63 50
3	20	8 0	74 75	65 75
4	21	4 14	74 75	65 75
5	22	1 0	74 75	61 25
Second Age.				
6	23	12 0	73 75	63 58
7	24	20 0	73 75	63 50
8	25	22 0	72 50	64 62
9	26	6 0	72 50	65 75
		60 0		

* The common pound of silk (*libra grossa*) contains eight light ounces.

† Corresponding to 17° Reaumur.

TABLE continued.

Mechanical
Processes.

1813. Days of Treatment.	Months.	Leaves and Stems.	Internal Tempe- rature.	External Tempe- rature.
Third Age.	May.	lbs. oz.	Fahren- heit.	Fahren- heit.
10	27	20 0	71° 37'	
11	28	60 0	71 37	
12	29	65 0	70 25	
13	30	35 0	70 25	
14	31	20 0	70 25	
		200 0		
Fourth Age.	June.			
15	1	...	70 25	
16	2	65 0	70 25	
17	3	110 0	89 12+	
18	4	150 0	69 12+	
19	5	170 0	69 12+	
20	6	85 0	69 12+	
21	7	20 0	69 12+	
22	8	...	69 12+	
		600 0		
Fifth Age.				
23	9	120 0	69 12+	
24	10	180 0	69 12+	
25	11	280 0	69 12+	
26	12	360 0	68 0	
27	13	540 0	68 0	
28	14	650 0	68 0	
29	15	600 0	68 0	
30	16	440 0	69 12+	
31	17	330 0	69 12+	
32	18	160 0	69 12+	
	Fifth age	3,660 0		
	Fourth age.	600 0		
	Third age	200 0		
	Second age.	60 0		
	First age	20 0		
		4,540 0		
	Uncon- sumed	475 0		
	Lost...	350 0		
	Total..	5,365 0		

Manufactures. *Management of Silkworms. Produce from Five Ounces of Ova.*

1814. Days.	Months, &c.	Leaves consumed.	Internal Tempera- ture.	External Tempera- ture at five o'clock A.M. Western exposure.	Hygrometer of Bellani.	Weather.
First period.	May.	lbs. oz.	Fahrenheit.			
1	23	1 7	72° 50' var	52° 25' +	..	Rain.
2	24	2 7	70 25	47 75	..	{ Rain occa- sionally.
3	25	3 0	70 25 var.	43 25	..	Rain and fair.
4	26	6 0	69 12	45 50	..	{ Cloudy and sunshine.
5	27	5 0	70 25	50 0	..	Cloudy.
6	28	2 14	71 37 +	54 50	..	Rain.
		20 0				
Second period.						
7	29	5 14	70 25	47 75	68°	Rain.
8	30	11 0	70 25	53 37 +	70	{ Mist and sun- shine.
9	31	15 14	68 0	56 75	64	Ditto.
10	June. 1	15 0	68 0	56 75	66	Rain.
11	2	7 0	68 0	63 50	66	{ Rain and sun- shine.
12	3	1 0	69 12	61 25	70	Cloudy.
		55 0				
Third period.						
13	4	14 0	69 12	54 50	68	{ Rain and sun- shine.
14	5	30 0	68 0	54 50	69	Cloudy, &c.
15	6	40 0	69 12 +	61 25	70	{ Rain and sun- shine.
16	7	60 0	69 12 +	56 75	75	Rain.
17	8	50 0	69 12 +	55 62 +	74	Rain.
18	9	20 0	69 12 +	52 25	79	{ Rain and sun- shine.
19	10	2 0	69 12 +	56 75	78	Ditto.
		216 0				
Fourth period.						
20	11	50 0	69 12 +	56 75	76	{ Rain and sun- shine.
21	12	85 0	69 12 +	63 50	75	Cloudy, &c.
22	13	120 0	68 0	64 62 +	71	Fine.
23	14	130 0	66 87 +	61 25	74	{ Cloudy and sunshine.
24	15	160 0	66 87 +	63 50	75	Sun and rain.
25	16	70 0	68 0	65 75	72	Ditto.
26	17	5 0	69 12	56 75	70	Fine.
		620 0				
Fifth period.						
27	18	120 0	68 0	60 12 +	72	Fine.
28	19	180 0	68 0	61 25	73	{ Rain and sun- shine.
29	20	240 0	68 0	56 75	73	Ditto.
30	21	310 0	66 87 +	59 0	75	Rain.
31	22	360 0	68 0	56 75	73	Cloudy and rain.
32	23	450 0	68 0	52 25	72	{ Rain and sun- shine.
33	24	550 0	68 0	54 50	74	Ditto.
34	25	650 0	68 0	53 37 +	73	Ditto.
35	26	500 0	69 12 +	54 50	73	Ditto.
36	27	280 0	69 12 +	54 50	73	Cloudy and rain.
37	28	180 0	69 12 +	50 0	72	{ Rain and sun- shine.
Fifth period		3820 0				
Fourth period		620 0				
Third period		216 0				
Second period		55 0				
First period		20 0				
		4731 0				
		400 0				
		290 0				
		5421 0				

For each ounce of ova, 1084 pounds of leaves have been taken from the tree. Mechanical Processes.

The silkworms, from five ounces of ova, have consumed the above 5420 pounds of leaves, and each produced 401 pounds of cocoons.

For each pound of cocoons there have been consumed about 13½ pounds of mulberry leaves.

The Temperature required for the Production of Silk Worms from the Ova, anterior to 23d May, 1814.

1814. Month.	Internal Temperature.	External Temperature.
	Fahrenheit.	Fahrenheit.
May 11	63° 50'	50° 26'
12	63 50	45 50
13	63 50	45 50
14	63 50	45 50
15	65 75	47 75
16	65 75	52 25
17	68 0	50 0
18	70 25	50 0
19	72 50	50 0
20	74 75	52 25
21	77 0	52 25
22	73 25	54 50
23	81 50	52 25

The external temperature was ascertained at five o'clock every morning, from a Western exposure.

During the thirteen days in which the silkworms were developed from the ova, 134 pounds of food were consumed. The pound of 28 ounces is to be understood, or two pounds Troy, equivalent to 0.7625 kilogrammes of France.

The following is the daily decrease in weight of 1000 ounces of cocoons in a room, the temperature of which is from 70° 25' Fahrenheit, to 72° 50' Fahrenheit :

Days.	oz.	oz.	Days.	oz.	oz.
First	1000		Seventh	960 less 6	
Second	991 less 9		Eighth	952 less 8	
Third	982 less 9		Ninth	943 less 9	
Fourth	975 less 7		Tenth	934 less 9	
Fifth	970 less 5		Eleventh	925 less 9	
Sixth	966 less 4				

So that the 1005 ounces have lost in ten days, during the mutation, 75 ounces. There is a gradual declension for the first five days inclusive, and a regular gradation for the five last days.

Eight ounces of ova have lost in five days, in weight, 100 grains; in eight days 360; and in ten days 440.

Six ounces of ova have lost in five days, in weight, 86 grains; in eight days 178; and in ten days 248.

Five ounces of ova have lost in five days, in weight, 60 grains; in eight days 168; and in ten days 216.

Four ounces of ova have lost in five days, in weight, 80 grains; in eight days 181; and in ten days 224.

Each grain contains about 68 ova, and an ounce weight 39.168 ova. The *ancia Milanese* contains 575 grains. The above number is to be understood of *fecundated* ova. Those which are badly impregnated contain 43.080, and are of a reddish colour; and of those not at all impregnated, and of a yellowish tinge, there are in the ounce 44.100.

Manufac-
tures.

The expense of the contingencies of the five ounces of crop, in 1814, are thus calculated by Count Dandolo.

Cost of 5 ounces of ova	15
Wood for fuel	11. 3
5500 pounds of leaves of mulberry, at 7 lire per 100 pounds	385
Expense of gathering the leaves..	96. 5
100 pounds at 32 soldi	16
Supplement	4. 10
Supplemental paper	4
Oil for light	9
Preservation phial	1. 10
Daily labour	100

Lire Milanese	642
Interest, &c. on capital	90

Total expense	732
401 pounds of cocoons obtained, which, being sold at 78 soldi per pound, produced	1563. 18

Net profit, lire

Note.—A *lira Milanese* is equal to about 8d., and there are 20 soldi in a *lira Milanese*.

The calculation, as above, includes not only interest on capital, but a valuation on the mulberry leaves, which is about one-half of the total expense.

The Augmentation and Diminution of the Silkworms in Weight and Size.

Increasing Progression.	Weight.
100 ova weigh about	1 grain
After the first change about	15
„ second „	94
„ third „	400
„ fourth „	1628
„ fifth „	9500

Increasing Progression.	Size.
The ova in the first instance about	1 line
After the first change, length about	4
„ second „	6
„ third „	12
„ fourth „	20
„ fifth „	40

Note.—In the 30 days, the silkworm has increased in weight 9500 times; and in 28 days, the animal has augmented in size about 40 times.

The French line is equal to 1.67 line English, calculating 100 lines English to the inch.

Decreasing Progression.	Grains.
100 silkworms, at their greatest size, weigh about	7760
100 chrysalis weigh	3900
100 females weigh	2990
100 males weigh	1700
100 females, after the ova are deposited	980
100 females naturally dead, and the eggs or ova deposited, &c.	350

In the space of about 28 days more, the silkworm has diminished in weight about 30 times. Thus the length of the silkworm, from the time of its greatest increase to the moment it is converted into the chrysalis, has diminished about three-fifths.

The chrysalis is the intermediate state between the worm and the winged insect.

Space occupied by each Ounce of Ova cultivated.

In the first age an area of square braccia	4
„ second „	8
„ third „	19
„ fourth „	45
„ fifth „	100

Note.—The *braccio di Milano* is divided into 12 ounces or inches, and corresponds to 5.95 palms, which may be calculated at 22 English inches nearly.

Amount in Weight of Mulberry Leaves consumed by the Silkworms. For every Ounce of Ova there have been consumed 1078 pounds of Leaves, divided as follows, viz.

	lbs.	Leaves, &c., left destroyed unused.	lbs.
First age eaten ...	4	First age	1
Second „ ...	12	Second	2
Third „ ...	40	Third	6
Fourth „ ...	120	Fourth	18
Fifth „ ...	732	Fifth	68
	908		95

In the course of the management of the silkworms, the 1073 pounds of leaves from the tree (from evaporation, &c.) will have lost 70 pounds.

Note.—There have been devoured by the silkworms about 515 pounds of pure mulberry leaves. The 1073 pounds of leaves, as taken from the tree, will yield 80 pounds of cocoons, calculating from one ounce of ova.

(1008.) The following is a more general view of the production of silk in the different Countries and districts in Europe where this business is conducted on the largest scale, for which we are indebted to Mr. Felkin.

At present, European silk may be properly classified as produced in the following districts, viz., mountainous France, the plains of Dauphny, &c., Piedmont and Nice, the Milanese, Tuscany, the Roman States, Neapolitan States, &c. In inquiring into the production of raw silk, the cultivation of the mulberry tree, so indispensable for the food of the worms, forms a particular object for investigation, the care of the worms is another, then the amount and quality of their produce, and the winding the cocoons.

The rose mulberry is almost the only kind planted throughout Europe for producing the food for silkworms. In its culture, the principal objects are the quality and quantity of its leaves; the coldest districts seem from various causes to be the most remarkable and appropriate to its growth, whether as regards care and skill in planting and pruning, or the relative quantity and quality of the leaves produced. The greatest amount of success has attended the cultivation of the mulberry in mountainous, dry, and barren districts; the following proportion being given as near the truth in reference to the produce of the mulberry in the following European silk districts.

A given number of trees produce in

	lbs.	Relative nutriment of trees in different soils.
The mountains of France	100	
Piedmont and Nice	85	
Plains of France	75	
Milanese	75	
Tuscany, Roman States	65	
Neapolitan States	60	

Of these, the former two, i. e. mountains of France

Manufac-
tures.

and Piedmont, produce leaves in the highest degree nutritious. Those of the plains of France and the Milanese are less nutritious by ten or fifteen per cent., and those of Tuscany and Naples by from twenty to thirty per cent.

A certain proof of the difference in the quantity of leaves produced by trees in these respective districts is found in the greater or less number of trees necessary to feed a certain number of worms; and we have a proof of difference in the quality of leaves, in the greater or less weight consumed producing a certain quantity of cocoons. The causes of these differences probably are, that trees succeed well in proportion to the purity of the air; the soil on which they are grown being more or less light and dry, and kept free from weeds or other vegetable matters. Each plucking of the leaves should be succeeded by careful pruning; and as standard trees are preferable on account of longevity, productiveness, and the greater adaption of their leaves to the health of the worms, they should be kept quite open in the centre of the head of the tree, by which mainly they are preserved from disease.

Human labour and skill are most easily obtained and applied to this cultivation, following the gradation above marked out in the respective silk districts. France had, in 1825, sufficient young mulberry trees planted to double its supply, if necessary, in ten years; Piedmont might increase one half in ten years, and the Milanese the same from trees already planted; the rest of Italy was stationary. It is found, in France, that the grafting on the wild stock tends much to the superiority of the leaf, both in respect to the health of the worm and the quantity of the silk. The two most fatal diseases with which the worms are affected are called the *gras* or the *jaune*, and may generally be traced to gross, overheated, or damp leaves.

Proportions
of food and
silk pro-
duced.

For every 1,000,000 pounds weight of raw silk produced in France, it is calculated that 250,000,000 pounds weight of leaves are consumed, and that 5,000,000 trees, of the average age of thirty years, are stripped to furnish them. In breeding silkworms, the essentials are, a sufficient supply of heat, fresh air, and recently gathered dry mulberry leaves. European recoils succeed best in the hands of persons who invest money in them for the sake of profit; but the largest proportion of the worms is fed by peasants on their own account, as an additional means of support; and, owing to the little space their dwellings afford, they only get to spin on an average, upon the scale of an ounce of eggs hatched, 33,000. In mountainous France, in which one-half are chamber recoils; and in these for each ounce hatched, 20,000 worms spin 85 pound cocoons, and one-half cottage recoils, in which 12,500 worms spin 55 pound cocoons.

In Piedmont, in which one-fourth are chamber recoils; and in these, for each ounce hatched, 18,500 worms spin 80 pound cocoons, and three-fourths cottage recoils, in which 11,500 worms spin 50 pound cocoons.

In the plains of France, one-fourth are chamber recoils; and in these, for each ounce hatched, 13,500 worms spin 60 pound cocoons, and three-fourths cottage recoils, in which 10,500 worms spin 45 pound cocoons. In the Milanese, one-fourth are chamber recoils; and in these, for each ounce hatched, 16,500 worms spin 70 pound cocoons, and three-fourths cottage recoils, in which 10,500 worms spin 45 pound cocoons. In Tuscany and Roman States, one-fourth are chamber recoils; and in these Countries, for each ounce

hatched, 11,500 worms spin 50 pound cocoons, and three-fourths cottage recoils, in which 9300 worms spin 40 pound cocoons. In the Neapolitan States, all cottage recoils, in which 9200 worms spin 40 pound cocoons.

Mechanical
Processes.

The price of cocoons is highest in those Countries where the recoil is best. The respective prices of the recoil, in 1825, (which was below an average one,) for ordinary fair parcels, Doppions and Chiques inclusive, were

Different
prices of
the cocoons.

	s.	d.
Mountainous France, for 16 ounces English	1	6
Piedmont, plains of France, and the Milanese, ditto	1	4
Tuscany, Roman States, and Naples, ditto	1	0
Calabria, ditto	0	10
Spain, ditto	1	2

The weight of silk produced in the year 1825, in the respective districts, and the average prices of fair silks, were as follows:

	lbs.	Mean Price per lb.
Mountainous France ..	750,000 of 16 oz. English, at	24s.
Piedmont	1,440,000	23
Plains of France	850,000	20
Milanese	2,650,000	18
Tuscany	100,000	16
Roman States (supposed)	500,000	17
Ditto Eastern ditto ...	500,000	24
Naples	100,000	18
Calabria	300,000	12
Spain, amount unknown.		

In consequence of new light being thrown upon the management of recoils within a few years, those of mountainous France and of the Milanese have been much improved, and are increased full one-third; those of Piedmont and of the plains of France are stationary: the production of silk in the other districts seem to have somewhat declined, probably owing to political causes. In the reeling of cocoons, care and skill produce the chief difference in the value of the silk; it is, however, to be remarked, that the best cocoons are certainly the Piedmontese; those produced in the mountains of France are scarcely inferior; the other districts produce them of nearly equal quality to each other, but all are inferior to the above. The excellence of the silk reeled in the higher districts of France has obtained for it a great demand in the French market, and this would probably be much larger were the English market open to its sale. The nerve of Piedmontese silk, and that of Fossombrone, has mainly contributed to keep up their price; this quality is, however, shared by the silk produced in all mountainous districts. The high priced silks are principally reeled in filatures, the lower by the peasantry.

Improvements have taken place in reeling cocoons in the higher parts of France within the last twenty years which surpass the progress made in the previous two centuries; these consist principally in the increase of filature reeling, and in carefully sorting the cocoons, and giving regular instruction to the hands. The reels are generally turned by power, and the water is heated by steam, double threads are avoided, and thus regular fine silks are produced with great advantage. Reeling is somewhat improved in the Milanese, by the application, to a certain extent, of the same means as in France. Improvements in the manner of cultivating the trees have been generally and effectively introduced in the mountainous districts of France, and in Piedmont, where they present a striking contrast to the

Manufac-
tures.

ill-conditioned standard trees of Dauphiny, Lombardy, and the Southern Italian States.

The peasantry engaged in breeding silkworms in the various districts of Europe have as yet made but little progress in improvement, but the larger chambers often present great skill and attention to the requisite details; the rooms built for this purpose are now larger, more airy, and arranged so as to produce a great circulation of air suddenly. Great cleanliness, and giving the worms dry food, have been attended with the happiest results; the peasantry living in the highest ranges of the hills often bring down for sale excellent samples of cocoons.

Progressive
increase of
silk in
France.

The progress of the production of silk in France has been considerable.

In 1789 it was 1,000,000 pounds.

In 1820 „ 1,350,000 „

In 1825 „ 1,600,000 „

The consumption, in 1825, was 3,000,000 pounds, which quantity, and of sufficiently good quality, she may probably produce by the year 1840, if necessary. Prejudices are very general on several important points; as for instance, in favour of lopping off large branches from trees, instead of small and frequent prunings; of letting the trees grow in grass meadows or amongst corn, without digging around the roots, as is necessary six or eight times during the year. The loss in leaves from these causes has been estimated by some so high as a third of what might otherwise be obtained. The poor people often suffocate the worms, and generally those they preserve are very much weakened by being subjected to close heat; it is difficult to make them understand that confined air may kill the insects at seventy degrees, but that they may remain healthy if the air be in circulation, though the actual heat be ninety degrees; this accounts for a large proportion of the extra loss in the peasants' breed of worms. They conceive they gain by reeling their own silk, but so much are they mistaken that there is no doubt they lose ten per cent. at least. The reeler by profession does not gain more than from ten to fifteen per cent. after he has paid all expenses, and runs considerable risks, although he produces from similar cocoons a far superior article.

Season for
reeling.

The owners of filatures have a great prejudice against reeling longer than during July, August, and September; certainly this period might be considerably extended without injury to the cocoons or the silk, and with great advantage to the persons employed. It is possible also to reel at less speed than is usual, if increased care and time be desirable. But the most important error, and one that has hitherto universally prevailed, is that which supposes all coarse reeled silks must be necessarily irregular also. It is just as possible to produce a coarse even thread as a fine one; and the advantage gained by reeling even thick silks must be apparent to those who know the waste and expense attending throwing fine silks to be used for various purposes, where even thick silks are necessary, and which must be superadded to the increase of cost of reeling fine silks.

Manufac-
ture.

(1009.) *Manufacture of silk.*—Having in the preceding pages given as complete an account as our limits will admit of the management and produce of the raw silk, it remains for us now to trace it through its several operations till it is in a state fit for the weaver, as we have done in the other materials already treated of.

Reeling.

Reeling the silk from the cocoons.—The cocoons become an article of trade as soon as the insect inside has

been killed by exposing them to the heat of the sun, or of an oven, or to the steam of boiling water: they are now to be wound. To effect this the balls are thrown into a vessel of water, having a charcoal fire beneath to preserve the water always of a proper temperature, and near this vessel is placed the reel on which the silk is to be wound. In this operation, it is to be understood that the ends of several cocoons are joined and reeled together out of the vessel of hot water above described, which softens their natural gum and causes the fibres to stick together in the form of one thread, and as often as a thread of any single cocoon breaks or comes to an end its place is supplied by a new one, so that, by continually keeping up the same number, the united thread may be wound to any length; these joinings are not made by a knot, but the new end is simply laid on the compound thread, to which it will adhere by its gum. In the commencement of the operation, after the cocoons have lain a few minutes in the hot water to soften their gum, the person by whom this work is done stirs up or brushes the cocoons with a whisk or birch rod cut rather short, and to this the loose threads of the cocoons will adhere and the ends are thus drawn out of the water; they are then taken, commonly four together, as twisted with the fingers, then passed through an eye made of wire, and thence to the reel; four other ends are in like manner passed through another eye to the reel so that two skeins are reeled at the same time; one person, commonly a child, turns the reel, and the other, generally a woman, attends to mending the threads. The reel is so constructed with cog-work that it has in its revolution a slight lateral motion, so that the thread of one revolution does not overlay the other, for if it did the natural gumminess would cause these threads to adhere: this lateral motion is such as to extend the breadth of each skein on the reel about three inches, by which time the gum is sufficiently dry to prevent the sticking; it then, therefore, traverses back again, and thus the work proceeds till the skeins are completed. All kinds of silk which are simply drawn from the cocoons by the reeling are called raw silk, but are denominated fine or coarse according to the number of fibres of which the thread is composed.

Mechanical
Processes.

(1010.) *Winding.*—In the state last described the raw silk is generally imported into this Country, and the first process it undergoes here is the *winding*, that is transferring it from the form of skeins on to bobbins. This process was formerly done by hand, and the machine carried four or more reels and as many bobbins, on which the silk was received, but at present, in our large silk mills, all these operations are performed by machinery; a number of reels extending to a great length, lying horizontally, receive as many skeins of silk, and on each side is an equal number of bobbins, the whole of which are put in motion by the machinery driven by the steam-engine or other first mover. The winding requires the unwearied attention of children to mend the threads that break, as well in this process as in the next, and it is by no means uncommon in our largest mills to have six or eight hundred or a thousand of these little operators busily employed. The old reel or swift consisted of four double arms so as to form a square, with a contrivance to stretch the skein to a proper tightness; but the modern swift has six single arms instead of four double ones, these arms being small flat tubes made to contain the stems of wire forks which receive the skeins instead of the bands in the common swift. These forks admit of being drawn out from the tubes

Winding.

Manu-
factures.

till the swift is sufficiently enlarged to extend the silk to its proper tightness; and instead of the weights formerly used in the old machine to keep the thread to its proper tightness to be received on the bobbin, this is in these done by small springs for the purpose.

Doubling
and tram-
ming.

(1011.) *Doubling and tramming.*—The silk being by the preceding process transferred from the skeins to the bobbins, the next operation is that of tramming, which consists in laying two, three, or more threads together prior to the throwing or organzining. This machine is very variously constructed, but the conditions absolutely essential in all are the following: first, that the silk may pass off easily and without entangling from the delivering bobbins; secondly, that a small and equal degree of tension be applied to the threads as they pass from the delivering bobbins to the receiving one, so that the compound thread shall be perfectly even, which would obviously not be the case if one of the component threads were quite loose while the others were drawn straight; thirdly, that the receiving bobbin cease to revolve as soon as any one of the component threads happens to break, (an accident which not unfrequently occurs,) as without such contrivance a thread would be produced of variable thickness, from the casual omission of one or more of the component threads.

The operation of tramming, in some of the best constructed mills, is performed in the following manner.

The delivering bobbins (varying in number from two to four, according to the intended thickness of the compound thread) are placed upon as many vertical spindles, the vertical position allowing the thread to quit the bobbins without any revolution or motion of the bobbins themselves. Some way above the bobbins the threads pass singly between two horizontal slips of cloth or felt, which, by their friction, give at the same time a certain degree of tension to the threads, and clear them from dust or any other light matter. Each thread then passes through the eye of what is called its drop wire; whence they all converge towards and unite in the eye of the guide wire, from which the compound thread is delivered and distributed on the surface of the receiving bobbins as it revolves.

Each drop wire consists of a piece of wire turned up so as to form a right angle, of which the vertical leg is about two inches long, and is terminated by an eye through which the thread passes, and the horizontal leg is about four inches long, terminating likewise in an eye, through which passes a pin connecting all the drops, and thus forming a pivot on which each is capable of moving freely. Each thread, in passing through the eye of its drop wire, slips down a little, and, being in a state of moderate tension, supports it at the elevation of half an inch or more above the position to which it would otherwise descend. When, therefore, a thread breaks, its drop wire immediately falls, and strikes on the edge of a wire frame moving on a horizontal pivot, and so adjusted that the weight of the drop wire immediately inclines downwards that side which it touches and consequently raises the opposite side. To this opposite side a tail wire is attached, which, when raised, catches on a kind of ratchet wheel fixed on the same spindle as the revolving bobbin, and consequently stops it. The broken thread being repaired, it is again passed through the eye of the drop wire, and supports it above the frame; the opposite end of the frame then becomes preponderant, the tail or stop descends out of the way of the ratchet wheel, and the revolution of the receiving bobbin again commences.

VOL. VIII.

(1012.) *Throwing or twisting.*—The bobbins being thus filled with compound threads, the next process is that of twisting them into one. This machine, as well as the doubling and tramming, winding, &c., has been much varied in its form of late years; in some machines the bobbins are furnished with a flier and made to revolve by an endless strap which drives a great many bobbins at the same time, by which the twisting is effected, the thread as twisted being received on a long horizontal reel whose revolution is so regulated as to allow of a proper twist being given to the silk. In others, the silk is twisted and received on other bobbins. It would be useless to attempt to give descriptions and drawings of all the various plans which the ingenuity of our silk manufacturers have introduced into their mills of late years. We shall therefore content ourselves with giving one entire process from the winding to the throwing, as described by Mr. Badnall, of Leak, in Staffordshire, for which he obtained a Patent in 1825. See plate lxxi., Silk Manufacture.

Here fig. 1, 2 represent a side view and plan of a winding machine. A, A are swifts, on which the hank of silk is placed or stretched in the ordinary manner. B, B are pulleys firmly attached to the axis of each swift; with a groove in them from which a band passes round the smaller pulley C C. Motion is communicated from these by the driving wheels D, D, which are themselves put in motion by any first mover.

The periphery of the driving wheels and pulleys coming in contact with each other, when the former are set in motion, the latter must revolve also, and, consequently, the swift also which bears the silk. Upon the periphery of the driving wheels are placed small wheels E, E, to which the spindles are attached which carry the bobbins upon which the silk is intended to be wound. This is best seen in fig. 2, where *a, a* represent the bobbins, F, F, fig. 1, are levers which act under the pivots of the spindle wheels E, E, upon any tension being applied to their longer arms, the fulcra being placed as near as convenient to the point where the shorter arm of the lever comes in contact with the pivots of the wheels.

On power being communicated to the driving wheel, motion, as already explained, is given to the pulley C C, B B, and to the small wheels E, E, which carry the bobbins. The result is, that a revolution of the swift and a corresponding one of the bobbin is effected, and so proportioned that the latter receives the thread at exactly the rate at which it is delivered from the former. To regulate, however, any variation caused by the increase of silk on the bobbin as it becomes filled, and its consequent increased bulk and decrease of the hank or skein, the levers F, F are brought into action; for on the slightest increased tension of the thread or threads which pass over the levers, the pivots of the wheels E, E are immediately acted upon, and are consequently raised from contact with the driving wheels D, D, and the speed of the bobbin retarded until a further supply of silk is given off from the swift. It is proper to state that the silk is made to pass over the glass rail H H, and thence over the levers F, F through the eyes or guiders G, G, and thence to the bobbins.

Fig. 3 represents another arrangement intended for effecting the same object, and for which, in many cases, it is supposed to be preferable. Here A is the driving wheel, B the receiving bobbin, C the compensating lever; but instead of employing a swift, the silk is

Mechanical
Processes.
Throwing
or twisting.
Pl. lxxi.
Fig. 1, 2.

Manufactures.

stretched on two cylinders D, E, of tin or other material, technically called *rise heads*; the upper one D, resting on the driving wheel, is acted upon in the same manner as the band wheel C in the former figures. It will, therefore, be readily seen that the silk being stretched on the cylinders, and the upper one put in motion by the driving wheel, it will revolve in the manner of an endless strap or band, giving off its thread to the receiving bobbin, as shown in the figure.

Fig. 4, 5.

The lever C acts in this arrangement exactly in the same manner as already described, but, to prevent the thread from getting entangled, it is made to pass over a plate of tin or other suitable material, F F, of the same breadth as the skein of silk, its sides being turned up to prevent the silk running off; this is shown detached in fig. 4.

The lower cylinder E may be moved to a greater or less distance from the upper D to accommodate that distance to the opening of the skein of silk; this is effected by the screw and slide G. In order to allow the plane F F to be accommodated likewise to the cylinders, it is divided into two or more pieces of any length, which being placed as at *a, b, c, d*, one under another, admit of any degree of extension short of the united length of the pieces of which it is composed.

In fig. 1, *x* represents a small ratchet, the object of which is to prevent the silk from being wound off again from the bobbin in case of its sticking in the skein; this is seen more clearly in fig. 5.

Doubling machine.
Fig. 6, 7, 8, 9.

(1013.) The *doubling machine* is represented in elevation and plan in fig. 6, 7. Any number of bobbins, on which the silk has been previously wound, are placed in an upright position on any suitable frame or board B B, and, according to the number of threads wanted to be doubled, such number are placed between the rods or bars C, C, C, (which are of glass,) and separately conveyed through small loops or eyes of the wires *a, a, a*, and thence through the guide loop or eye *b* to the receiving bobbin D. The glass rods or bars C, C, C, are fixed in an upper and lower frame, the upper one movable on hinges *c, c*, so that, instead of passing the silk under one bar and over the other, the same is effected by the top frame being raised, and, when the threads are passed over the lower frame, let down again, which falls upon the silk and forms angles or curves resembling those shown in fig. 8, by which means sufficient friction is produced to lay the silk with proper tightness on the bobbin D, and to keep the loops or eyes of the wires *a, a, a* elevated as long as the threads continue whole. E is a lever exactly balanced, one end of which has a plate of tin attached to it, and this plate is fixed exactly under the wires *a, a, a*, so that if any of the said wires, by the breaking of the thread which elevates them, should fall, the end of the lever upon which it falls would immediately preponderate and the opposite end be raised, thereby stopping the motion of the receiving bobbin, in a manner similar to that mentioned in our preceding general description. Fig. 9 represents a bobbin with a circular rim of polished metal on its top, the object of which is to prevent breaking the threads, which frequently occurs where the common guider or fly is used.

Spinning and doubling.
Fig. 10, 11, 12.

(1014.) *Spinning, doubling, and throwing*.—Fig. 10, 11 are a side and front view of the improved machine for spinning, doubling, and throwing at one operation, which was patented by Mr. Badnell in 1823, and of which the following is the specification.

“Fig. 12 represents a bobbin and guider or flier, as commonly used, to which guider I chiefly attribute the greatest portion of the waste made in the throwing of silk, the causes of which are obvious. The guider or flier A moves loosely on the spindle; to this spindle the bobbin B is firmly attached. Considerable friction and strain is therefore produced on the silk by the power required to draw round the guider or flier A, independently of the angular position which it necessarily takes in being drawn off the bobbin. To counteract this, therefore, the circular metallic rim, represented in fig. 9, is substituted, whether attached to the bobbin or placed loosely on the top of it.

“In the figs. 10, 11, A, A are bobbins upon which the silk has been previously wound or doubled, according to the description of the manufactured article required; at the top of these bobbins are either attached, or placed loosely, the circular rims B, which are called waste preventers, and which are made to extend about one-fourth of an inch beyond the circumference of the bobbin. C is a rectangular bar of wood or metal covered with woollen cloth, or any other material capable of producing friction. Over this bar, and once or more round it, the ends of the silk are taken from the bobbins A, A, and conveyed through the loops or eyes D, D through the rollers E, E to the receiving bobbin F. Motion is given to the spinning spindles G, G, and to the throwing spindle H, by an endless strap, band, or chain I I, passing between their whorls or stockings, as described in the drawings, which strap is actuated by a drum or cylinder in the usual manner. It is evident, on reference to the figure, that if the strap be set in motion, the spindles G, G will be revolving in an opposite direction to the spindle H; and if the rollers be also set in motion, which motion is regulated so as to suit the exact quantity of twist the kind of silk requires, the silk will be drawn from the bobbins A, A, and received on the bobbin F, in the usual manner of cotton spinning. The bobbin F being loose upon its spindle, and the flier attached fast to it, a sufficient friction for all necessary purposes is produced by passing the silk round the covered rail or bar C. By this contrivance the guider A, as described in fig. 12, is rendered useless, and consequently the breakage of threads very materially diminished. Independent of the above great advantage arising from the use of the ‘waste preventers,’ they allow a very great increase in the speed, to which the guiders commonly in use were an insurmountable obstacle, in consequence of the centrifugal action being so great as to cause an extension of the wires when they very frequently came in contact with each other; and this happened particularly in this method of throwing, when it was necessary to have the receiving or throwing spindle as close as possible to the giving off or spinning spindles. In case the thread or threads from either of the spinning bobbins A, A, which unite at the rollers, should break, a cutter, as represented in fig. 13, is provided, which is placed on the lower part of the frame K K, which frame also supports the rollers, and by passing the two ends of the silk over the cloth bar C C, then crossing the threads round each other, and then passing them through the upper loops or eyes D, D, they maintain, as long as they remain unbroken, a situation as shown in fig. 14; but as the points I, I of the cutter, as shown by fig. 13, are two small pieces of sharpened steel, on the breaking of either thread, the remaining one being liberated, will immediately come in

Fig. 13, 14

Manufac-
tures.

contact with one of the said pieces of steel and be instantly cut.

"According to the diameters of the whorls or stockings which are fixed upon the giving-off spindles G, G, and the receiving spindle H, will be the proportion of twist or spin between them, and according to the speed of the rollers will be the twist or spin given to the united threads. It is here necessary to state that, by means of the above-described cutter and circular metallic rim, with the cloth friction bar, the two operations of doubling and spinning may be performed at the same time. The mode of doing this will be easily understood by referring to fig. 10, and supposing the rollers E, E to have their place supplied by the ordinary receiving bobbins, while the receiving bobbin F of the mill is taken away all together. If, then, the two threads are carried from the two spinning bobbins A, A, in the manner described in the plate, to the receiving bobbin that has taken the place of the rollers E, E, they will be gathered on that bobbin, having been first spun by the revolutions of the two bobbins A, and thus doubling and spinning in one operation.

"In fig. 1, 2, I claim any means of giving motion to a swift, rise head, or any other reel upon which silk may be placed for the purpose of being wound on to the receiving bobbin at the same time, in conjunction with a compensating apparatus, or any imitation thereof whatever, whereby the same effect may be produced; that is, I claim any means, in conjunction with an apparatus, which can, through the agency of the silk, retard or accelerate the receiving bobbin whereby silk can be conveyed from a swift, rise head, or reel, on which it is placed to be wound, to a bobbin which is to receive it, without any friction or tension being employed upon it, except that which is necessary for its action upon the said apparatus, and consequent self-preservation, and for laying it with a proper tightness on the bobbin, and which may be increased or diminished at will, by increasing or diminishing the action of the said apparatus on the bobbin itself.

"In fig. 3, I claim the arrangement there described generally, and particularly the channel of metal or other material F F, for supporting the skein in its passage from one rise head to the other. In fig. 6, 7, I claim the use of rods or bars of glass, or any other suitable substance, as heretofore described, by passing the silk under and over, by which a sufficient degree of tension is produced to lay it well upon the receiving bobbin, whereby the wire guiders commonly in use are rendered unnecessary, and much breakage and waste consequently prevented; if one or two of these rods or bars be covered with woollen cloth, or any other suitable substance, it would tend much to clean and brighten the silk, and to prevent loose ends running up. In fig. 6, 7, I also claim the particular arrangement, as described in the drawings, of the loops and wires a, a, a, which are made so peculiarly light and small as to produce but the slightest tension on silk, and yet sufficiently heavy to answer every purpose.

"In fig. 10, 11, I claim the general arrangement of the machinery, the particular arrangement of the cloth bars, waste preventers with the cutter, and the application of the same peculiar arrangement of parts to the common spinning mills, for the purpose of doubling and spinning at one operation.

"Lastly, I claim, whether for this or any other purpose, the exclusive application of the circular polished metal

rims, or other suitable substance, whose surface is not liable to be chipped or injured in ordinary use, termed 'waste preventers, as a substitute for the old fliers.'

"R. BADNELL."

For the subsequent operations in the silk manufacture, see the general article WEAVING.

Woollen and Worsted Manufactures.

(1015.) The history of the woollen manufacture, like most of the other useful Arts of ancient date, is involved in some obscurity. The Greeks give the honour of the invention of spinning and weaving wool to Minerva; it is, however, supposed to be of Asiatic origin, and is referred to by Moses in the Bible, as existing at least fifteen hundred years before the Christian Era.

In the early period of manufactures, whether in wool, cotton, or flax, the first steps were nearly the same; except so far as each being a different material, each required some peculiar preliminary preparation to fit it for the use of the actual manufacturer. We have seen in what manner cotton and flax are prepared for the spinner; in this article we have to describe the processes used with wool to reduce it to a like state. This, in the first attempts, was probably effected by the fingers, and afterwards by the application of some kind of comb, the use of which is of unknown date, and is continued in some processes to the present day. The invention of the wheel and spindle is also of unknown origin, but has obviously been practised for many Ages. In the infancy of this Art, and for many centuries after, the making of cloth was merely a domestic occupation; the fleece was gathered from the sheep, washed, opened, spun, and woven under the same roof which witnessed the preparation and the grinding of corn; consequently we may assume that little of perfection was either effected or aimed at; but in proportion as Society advanced and a division of labour became convenient, improvements were made, not only in the Arts of spinning and weaving, but in that of breeding and selecting those animals, whether sheep or goats, which gave the finest fleece. The produce of white wool from sheep is said to be entirely the result of cultivation, and is unknown in those Countries where it is not employed as an object of manufacture or commerce. We may imagine that, in the earliest state of the woollen manufacture, when cloth was simply a substitute for the skin of a beast as clothing, little attention was paid to the colour or fineness of the wool; but as luxuries were introduced coloured garments were required, and the wool could no longer be taken indifferently from sheep of all tints, from the white to the dark brown or black. The grower began then, therefore, to pay particular attention to the whiteness of his fleece, which was essential to the cloth, when made, receiving the brilliant dyes which, even in a very remote period, were certainly given to it.

With respect to the woollen manufactures of the Greeks and Romans, we have very scanty information, although it is obvious that the clothing of armies so large as they sent out must alone have required considerable manufactures; and although we have so little information as to the actual processes employed, or respecting the establishments in which they were conducted, yet there are various circumstances to prove that the latter People carried the manufacture of fine woollen cloth to a considerable degree of perfection, and paid particular attention to the breed of

Mechanical
Processes.

Early
history.

Woollen
manufac-
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Romans.

Manufac-
tures.

their sheep. Pliny describes two breeds of sheep, the one having long, coarse hair, which was on that account called *hirtum*, or *hirsutum*, and from its hardness and rougher treatment *colonium*; the other was called *molle*, from the softness of its wool, and *generosum* or noble, from its excellence, which latter was sold at a very high price. This breed had other distinguishing names, as Tarentinum, Apulum, Calabrum, Atticum, and Græcum, from the neighbourhood or district whence the fleece was derived. This breed was also called Asianum as the place of its origin, and is supposed to be the same as that we now call the Merino.

That the Romans imported their Tarentine sheep into their Western colonies, with the art of weaving fine cloth, is stated both by Strabo and Pliny. The former writer, who flourished in the time of Augustus, says, that in Turditanian, in Portugal, at that time a part of Spain, "they formerly imported many garments, but now their wool is better than that of the Corani, and so beautiful that a ram for the purpose of breeding was sold for a talent, (£216 sterling,) and that fabrics of extraordinary thinness were made of this wool by the Saltratae." The wool here alluded to is supposed to be that of Cashmere, of which shawls are manufactured in Persia. It appears that all classes of the Roman people wore woollen clothes, that of the lower Orders, no doubt, of an inferior description, but amongst the higher classes very fine cloth was used, and amongst these, probably, as a great object of luxury, was included cloth in imitation of the Indian shawl. When the Roman Empire, on its fall, was overrun by nations of Barbarians, whatever might have been the perfection at which it had arrived in the manufacture of the finer fabrics, the Art was entirely lost, and only that part saved from destruction which was connected with the making of the warmest and coarsest kinds of cloth.

Manufac-
tures in the
Low Coun-
tries.

In the middle of the Xth Century it seems to have revived a little in the Low Countries, in which it remained the source of great opulence to the people for more than four hundred years. In the first instance the wool which was used was the produce of their own pasture; but as the manufacture extended itself, the demand for wool became too great to be supplied by themselves, and was therefore derived from other Countries. The wealth which was thus acquired was seen by other nations, and people crowded into the Country, engaged in its commerce, and pushed their speculations with increasing vigour for another century and a half, when an inundation of the sea, which threatened the whole nation with ruin, caused a dispersion of the manufacturers, and spread the Art over a much larger space. This gave to the trade a new impetus, and was the means of establishing a connection between the Netherlands and foreign Countries, which ultimately proved of the highest importance to commerce. It contributed to a speedy recovery of the woollen manufacture from the ruin which seemed to threaten it, and gave a striking instance of the facility of re-establishing the Arts in any Country where they have once flourished under the patronage of a government liberal enough to encourage and sufficiently powerful to protect them even in situations attended with natural disadvantages. The influence of these manufactures upon the fleeces of the Low Countries must have been very considerable; for, before the year 960, there is no reason to suppose that their quality was

superior to those of the neighbouring districts, and yet Flanders and Brabant became famous for their cloths even before they imported much foreign wool. Mechanical Processes.

About the year 1200, the merchants began to import the wools of other Countries, to extend their connection much more widely, and they grew by this means much more rich and powerful. The ships of Spain and England carried their fleeces almost to the doors of the manufactories, and received in return little more than a supply of manufactured goods, which was probably not great, although it is said that the fleece formed full two-thirds of the value of the ewe that produced it, at least in England.

Soon after this time the woollen manufactures took root in many of the Countries of Europe. In Spain it had never, perhaps, been lost; and it is said that in 1218, not less than 16,000 looms were employed in the city of Seville alone. In 1353, the exportation of certain kinds of cloth was carried to such an extent in Spain, that it is said 935 bales of these goods were taken on board a Spanish vessel on its way to Alexandria, and 1000 bales on board another vessel in 1412; and in 1446, wool was sent from England to that Country to be manufactured into cloth, and returned. From Spain the manufacture travelled into Italy and France; and in 1646 Nicholas Cadeau, a Frenchman, had Letters Patent for twenty years, for making sedan, black and coloured cloths, like those of Holland, of the finest Spanish wool. Manufactures in Spain and France.

The inhabitants of the North of Europe were not at first able to manufacture fine Spanish wool without a mixture with that which was longer and coarser; but what in the beginning was a matter of great necessity, became afterwards an object of choice, and accordingly the more skilful clothiers, as well in Holland as elsewhere, either discarding the finer and dearer Spanish wool, or mixing it with the cheaper and coarser English, forming a warp of the latter which they covered with a woof of the former, contrived to make a cheap and serviceable cloth, which pleased the eye equally well with the more costly fabrics of entire Spanish wool. This, however, was carefully concealed at the time, but was afterwards candidly acknowledged by writers actually engaged in the commerce of wool, and sufficiently refuted the prejudices which had prevailed, from the middle of the XVIth Century to the middle of the XVIIth, that the wools of other Countries than that of Spain were inapplicable to the manufacture of very good and fine cloths.

In 1659, a Treaty was entered into by the Spanish and French Governments which enabled the latter freely to obtain the wool of the former, and thus to gain great advantage over the English in the Levant trade. From the proximity of the French to the woollen manufactures in the North of Spain, it might have been expected that the French would have engaged earlier in this manufacture; but owing to their frequent wars, and to their attention having been directed to the manufacture of silk, they do not appear to have commenced the fabrication of woollens for exportation extensively before the XVIth Century; but about this time France made great progress with her manufactures of wool, and in securing the export trade, particularly that of Tartary, for which she was better situated than England or Holland. The nature of her trade to warm climates directed her attention to the fabrication of the lighter and finer cloths; in consequence of which she preserved

Manufac-
tures.

the greater part of the Turkey trade even to the outbreak of the French Revolution, and at a much earlier date fine French cloths had attained a celebrity for their superiority of texture and dye over those of any other Country of Europe; and how long she might have retained the monopoly, founded on this preference, it is impossible to say, had not the Revocation of the Edict of Nantes driven many of her best hands, both in the woollen and worsted trade, to seek for shelter in other Countries, to which they carried the Art, hitherto almost exclusively French. In spite of this, however, although thenceforward may be dated the downfall of the French superiority, that Country supplied the greater part of her own population, then about twenty millions, with cloth, besides her foreign exports. Under Napoleon, the best Merino flocks were imported from Spain, and spread over the country very extensively, so that much fine wool has, since the Peace, been imported into England, as will be seen by the Tables we have given in a subsequent page. All has now, perhaps, been said that is requisite concerning the rise and progress of the woollen manufactures in Europe generally; we must now turn to Britain in particular, at present the great seat of manufactures of nearly every description, which, by means of her coals, machinery, and facilities of transport, she is able to bring with advantage into nearly every market of the world.

History of
the woollen
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England.

Woollen manufactures of England.—There appears some reason to suppose that the Romans, during their possession of England, established a manufacture of woollen cloths at Winchester; but the first distinct notice of a body of manufacturers occurs in the reign of Henry I., who are supposed to have been some of those driven out of Holland by the terrific inundation to which we have already referred. They are said to have been well received, and first placed in the neighbourhood of Carlisle, and towards Scotland, but were afterwards transferred to Pembrokeshire. This removal was made in the time of Henry I.; but mention is made of other cloth weavers in this reign both in London and Oxford. In the reign of Henry II. there were weavers at Nottingham, Huntingdon, York, Oxford, London, and Winchester, all of whom paid fines to the King for the privilege of carrying on their trades. There were also cloth dealers not only in the places above named, but in Norwich, Gloucester, Newcastle-upon-Tyne, Berkhamsted, Chesterfield, and in several towns in Lincolnshire, who also paid fines to the King for the privilege they possessed of buying, dyeing, and selling cloths. In the 31st of Henry II. the weavers of London received a confirmation of their guild with all the privileges they enjoyed under Henry I., and in their Patent it was directed, that if any weaver mixed Spanish wool with English in making cloth the magistrate should seize and burn it; this order was given under the pretence of the inferiority of the Spanish wool, but its real object was to encourage the growth of English wool, and to increase its quantity for the benefit of the King's revenue.

In the reign of Henry III. an Act was passed limiting the breadth of broad cloths, russets, &c. to two yards within the lists; and in 1284 another Act permitting foreign merchants to rent houses and to buy and sell their own commodities without any interruption from the citizens. In 1331, John Kemp, a master manufacturer from Flanders, received a protection to establish himself in England, with a number of dyers

and fullers, to carry on his trade; and in the following years several manufacturers came over from Brabant and Zealand. These were distributed over the country; at Norwich for the manufacture of woollen fustians, at Sudbury for baize, at Colchester for sayes and serges, in Kent for broad cloth, Devonshire kersies, Worcestershire, Yorkshire, &c., for cloth generally, and some other places.

In 1336, two woollen manufacturers from Brabant settled at York under the King's protection, who are supposed to have laid the foundation of the woollen and worsted manufactures which have since so extensively flourished in the Western part of that County. A few years after Thomas Blanket established a manufacture of coarse white cloth at Bristol, from whom the term blanket is supposed to be derived. In his first attempt he was so harassed by the Mayor and other members of that Corporation for fees, fines, and impositions, that he petitioned the King for Letters Patent to allow him the free exercise of his profession or trade without "impediment, calumny, or exaction."

At this time, 1357, the woollen trade of England was considerable, and the exports of some importance, as appears by the following Table of 28th of Edward III., said to be found in a record in the Exchequer, and published by Edward Misseldon, merchant, in 1623.

Exports and Imports of Woollen Cloths in 1355.

Export of
woollen
cloths in
1355.

<i>Exports.</i>		£.	s.	d.
Thirty-one thousand six hundred and fifty-one sacks and a half of wool, at £6 value each sack, amount to	189,909	0	0	
Three thousand thirty-six hundred and sixty-five felts, at 40s. value each hundred at six score, amount to	6,073	1	8	
Whereof the custom amounts to	81,624	1	1	
Fourteen last, seventeen dicker, and five hides of leather, after £6 value the last, amount to	89	5	0	
Whereof the custom amounts to	6	17	6	
Four thousand seven hundred and seventy-four cloths and a half of worsted, after £2 value the cloth, is	9,549	0	0	
Eight thousand and sixty-one pieces and a half of worsted, after 16s. 8d. value the piece, is...	6,717	18	4	
Whereof the custom amounts to	215	13	7	
Summary of the out-carried goods in value and custom	£294,184	17	2	

Imports.

One thousand eight hundred and thirty-two cloths, after £6 value the cloth, is	10,992	0	0
Whereof the custom amounts to	91	12	0

There is in the account from which this is taken no statement of wool imported; it would appear, therefore, that at this period the English manufactures employed only home-grown wool; and it will also be observed, that the cloth imported was more valuable than the exported, so that probably the former was made of the finer Spanish wools, and the latter of the coarser wools of the English flocks.

Many fraudulent practices having been had recourse to by English cloth manufacturers, an Act was passed in the reign of Richard II., which states, "Forasmuch as divers plain cloths, wrought in the Counties of Dorset, Somerset, Bristol, and Gloucester, be tacked and folded for sale, of which the greater part be broken, bruised, and not agreeing in colour, neither according to the breadth, and in no manner to the part of the same cloths

Mechanical
Processes.

Manufac-
tures.

showed outside, but falsely wrought with divers wools, to the great damage of the people, inasmuch that the merchants that buy the same, and carry them out of the realm to sell to strangers, be many times in danger of being slain, and sometimes imprisoned and put to fine and ransom, therefore it is ordained, that no plain cloth tacked and folded shall be set to sale within the same Counties." The same Act permits certain coarse cloth of wool to be made of the breadth of three-quarters, and appoints one weight and measure through the Kingdom, except in the County of Lancaster. Another Act allows cloth to be made of any breadth and length, provided "aulnage and other duties be paid on the same and no deceit be practised."

During this reign it appears that, notwithstanding the great extent of the woollen manufactures, the English annually exported about 130,000 packs of wool, paying a duty of £160,000.

Other Acts were passed in the reigns of Henry IV. and Henry VI. for regulating and enforcing various conditions on the manufacturer, amongst which was one in the latter reign appointing two cloth searchers to every County, whose duty was to inspect, search, and measure every piece, and to seal the same, for which duty they received one penny per piece. In this reign, also, the exportation of woollen yarn was prohibited, although that of wool was permitted.

Other regulations were introduced in the subsequent reigns, one of which, in that of Henry VII., fixed a maximum of price limiting the selling prices per yard for fine scarlet cloth to 16s., and that of other colours to 11s., imposing a fine of 40s. per yard for any one transgressing this Statute. In the reign of Henry VIII., both the woollen and worsted trade was very flourishing till this monarch entered into his wars with the Emperor Charles, which greatly affected the export trade to Spain and the Low Countries, so that the goods sent up to Blackwell-hall in London, which had been appointed in 1357 as a general cloth mart, found no purchasers. In 1551, one Company alone, privileged under the denomination of the merchants of the Stillyard, exported 44,000 pieces of cloths of all sorts, 60,000 white cloths, the former valued at £400,000, and the latter at £600,000, besides wools and woolfels. In the subsequent reigns of Edward VI., Mary, and in the beginning of that of Elizabeth, the woollen manufactures seem to have declined, principally, perhaps, in consequence of the injudicious regulations introduced from time to time granting privileges to one County or district and denying it to another. In one County wool might be bought and sold, in another it was prohibited; the fixing a maximum of price and various other vexatious enactments; but in the latter part of the reign of Elizabeth many of these oppressive Statutes were repealed. Hitherto the manufacturing of cloths had been confined to corporate towns, but the privilege was now extended to all persons resident in the Counties of Somerset, Gloucester, and Wilts; why other Counties had not the like privilege does not appear. This Act, however, served to extend the manufacture over a very large district, in which it has continued to flourish to the present time. Many other Acts were passed in this reign much at variance with our present ideas of freedom of trade, but wool was allowed to be exported. The internal tranquillity which the Country enjoyed during this long reign, the influx of foreign makers of new kinds of worsted goods and other articles, the opening new

foreign markets, viz., with Turkey and the Barbary States, all contributed to extend the woollen manufactures so much that the merchant adventurers alone, towards the commencement of the XVIIth Century, exported cloths and wool to the amount of one million sterling.

In the following reign new laws were made respecting the exportation of cloth; hitherto it was chiefly white cloths which had been exported, but this was now considered bad policy, as it was supposed that thereby the profit of the dyeing and dressing was lost to the nation. A letter exists, addressed to James I., in which it is stated, "that there have been eighty thousand undressed and undyed cloths exported yearly, by which the Kingdom has been deprived of £400,000 for the last fifty five years, which is nearly £20,000,000 that would have been gained by the labour of the workmen in that time, with the merchants' gains in bringing in dyeing wares, and return of cloth dressed and dyed, with other benefits to the realm." The writer, who has been supposed by some to have been Sir Walter Raleigh, states, that there had also been exported at that time annually 50,000 Devonshire white cloths, baizes, and kersies, whereby had been lost £5,000,000 to the nation in labour and profit. These baizes, the writer states, were dyed at Amsterdam and shipped to Spain, Portugal, and other Kingdoms, under the name of Flemish baize, setting their own seal upon them, "so that we lose the very name of our home-bred commodities." The writer then concludes by asserting, that the nation loses £1,000,000 a year by the exportation of white cloths. All this was according to the spirit of the Age, when interferences of all sorts were called for and adopted; but the impolicy of this measure was soon discovered, for no sooner was the prohibition granted to prevent the exportation of any but dyed cloths, than the Dutch and Germans prohibited the importation of any but white cloths, so that it was soon found that the nation lost instead of gained by the measure. In the subsequent reigns of the Stuarts religious persecutions tended greatly to depress the woollen trade. The descendants of the French Protestants who had before settled in Norfolk and Suffolk, for the sake of enjoying their Religion in peace, were now again attacked in their place of refuge, and many families of them were driven over to New England, while others went to Holland, where they were allowed to settle, with the privilege of being exempt from taxes for seven years, and thus their skill and knowledge were rendered available to our competitors in the woollen and worsted trades.

In 1668, a person named Brewer brought over about fifty workmen who wrought and dyed fine woollen cloths, in the manufacture of which the English had hitherto been very deficient. This party received the protection of Charles II., and from them the English were first instructed how to manufacture cloth of the best Spanish wool, and also to dye their fine cloth at about forty per cent. less expense than they had formerly been able to do. Notwithstanding, however, this circumstance, it appears that the cloth trade declined during this reign, and that on a representation being made to the merchant adventurers for their neglect of it, they stated that the demand for English cloths failed in the foreign market, and that the white clothing had abated from 100,000 pieces annually to 11,000.

It was not till the reign of William III. that the manufactures of woollen cloths became firmly fixed and

Mechanical
Processes.

Manufactures. progressive in the Country, as will be seen by the returns of the exports. In the year of the Revolution the export of woollens alone was nearly £3,000,000, at which it remained pretty steady till 1715.

In 1718 the value of woollens exported was	£. 2,673,696
1719.....ditto.....	2,730,297
1720.....ditto.....	3,059,049
1721.....ditto.....	2,903,310
1722.....ditto.....	3,384,842
From 1739 to 1748 medium annual value..	3,327,059
From 1749 to 1753.....ditto.....	4,189,195
In 1816.....ditto.....	8,404,481

In the subsequent Tables will be seen the amount of Exportation from 1820 to 1831, the importation and other particulars, which will give a tolerable view of the state of the woollen manufactures since the introduction of the most recent improvements in machinery.

We have not in the preceding historical sketch made any particular distinction between the woollen and the worsted manufactures; the latter is supposed to have been introduced into this Country about the year 1336, and within a few years after that period had attained a considerable degree of importance, but in subsequent periods it was subject, like the woollen trade generally, to various fluctuations. Its exports and imports are included in the following Tables.

An Account of the Quantity of Foreign Wool imported into, and of Foreign and British Wool and Woollen Yarn exported from the United Kingdom, in each Year, from 1820 to 1831, both inclusive.

Years.	Foreign Wool Imported.	Foreign Wool Exported.	British Wool Exported.	Woollen Yarn Exported.
	lbs.	lbs.	lbs.	lbs.
1820	9,775,605	64,585	35,242	3,924
1821	16,622,567	291,318	34,226	9,121
1822	19,058,080	233,872	33,208	12,515
1823	19,366,725	200,776	28,563	6,423
1824	22,564,485	419,594	53,743	12,640
1825	43,816,966	678,034	112,424	76,961
1826	15,989,112	888,651	143,130	131,032
1827	29,115,341	760,109	278,552	255,708
1828	30,236,059	872,249	1,669,389	436,722
1829	21,516,649	406,566	1,332,097	589,558
1830	32,305,314	659,242	2,951,100	1,108,023
1831	31,625,029	1,025,962	3,494,275	1,592,455

Mechanical Processes. The above Table gives the total of the importation and exportation for the several years therein stated, and in the following three Tables will be found the particular importation and exportation, and the names of the Countries from or to which it is made. We have selected three years at nearly equal periods in order to show the progressive increase or decrease of our trade with these several Countries and Colonies.

A Return of the Quantity of Foreign Wool imported, and of British Wool and Yarn exported, with the Countries from or to which it was made, in the Years 1820, 1825, and 1832.

In 1820.

COUNTRIES.	Foreign Wool Imported.	Foreign Wool Exported.	British Wool Exported.	Woollen Yarn Exported.
	lbs.	lbs.	lbs.	lbs.
Russia	75,614	...	...	...
Sweden	...	...	...	...
Norway	...	...	...	...
Denmark	13,527	6,854	...	...
Prussia.....	107,101	...	...	...
Germany	5,113,442	411	...	159
The Netherlands	186,051	39,737	...	...
France	230,909	618	...	...
Portugal, Azores, & Madeira	95,187	...	...	...
Spain and the Canaries	3,536,229	...	...	...
Gibraltar.....	3,851	...	...	...
Italy.....	2,815	...	...	...
Malta.....	5,050	...	...	...
Ionian Islands	...	...	...	...
Turkey	195,184	...	...	...
Guernsey, Jersey, Alderney, } and Man	...	...	35,242	...
Morocco	...	...	...	...
Western Coast of Africa....	...	...	...	...
Cape of Good Hope	13,869	...	...	...
Mauritius.....	...	...	...	...
East Indies and St. Helena.	8,056	...	...	...
New South Wales and Van } Diemen's Land	99,415	...	...	...
British North American } Colonies	139	...	...	3,765
British West Indies	760	...	...	...
Foreign West Indies	...	...	...	...
United States of America ..	578	16,965	...	...
Brazil.....	4,277	...	...	...
Mexico	...	...	...	...
States of the Rio de la Plata	68,759	...	...	...
Chili	14,792	...	...	...
Peru	...	...	...	...
Total....	9,775 605	64,585	35,242	3,924

Manufactures.

Mechanical Processes.

In 1825				
COUNTRIES.	Foreign Wool Imported.	Foreign Wool Exported.	British Wool Exported.	Woollen Yarn Exported.
	lbs.	lbs.	bs.	lbs.
Russia	1,992,101	...	...	1,532
Sweden	3,497	...	...	...
Norway	302	...	...	54
Denmark	554,213	...	...	...
Prussia	131,100	...	...	2
Germany	28,799,661	14	4,568	24,850
The Netherlands	1,059,243	266,486	37,037	12,143
France	443,033	21,929	14,996	2,399
Portugal, Azores, & Mad.	968,994	...	77	1,353
Spain and the Canaries.	8,206,427	1,081	...	...
Gibraltar	19,250	...	178	131
Italy	230,415	...	...	3,127
Malta	72,131	...	...	6
Ionian Islands	25,983	...	...	...
Turkey	518,619	...	...	...
Guernsey, Jersey, Al- derney, and Man ...}	14,228	2,188	24,765	5,555
Morocco	...	...	...	...
Western Coast of Africa	...	...	...	675
Cape of Good Hope	27,619	...	...	110
Mauritius	...	...	127	750
East Indies & St. Helena	...	...	...	...
New South Wales and Van Diemen's Land }	323,995	...	...	...
British N. Amer. Colonies	70	1,170	6,594	5,074
British West Indies	...	...	258	100
Foreign West Indies ...	...	...	...	...
United States of America	80,468	385,166	22,564	14,484
Brazil	37	...	1,260	4,586
Mexico	...	...	...	...
States of Rio de la Plata	331,265	...	...	30
Chili	2	...	...	...
Peru	14,313	...	...	...
Total	43,816,966	678,034	112,424	76,961
In 1832.				
	lbs.	lbs.	lbs.	lbs.
Russia	855,680	2,596	414	44,834
Sweden	...	...	...	449
Norway	...	...	...	...
Denmark	302,848	...	...	205
Prussia	833,988	...	...	6,771
Germany	19,832,225	27,056	32,394	1,128,196
The Netherlands	209,144	435,599	3,416,963	425,751
France	1,973	67,772	736,482	3,361
Portugal, Azores, & Mad.	193,544	...	...	2,378
Spain and the Canaries.	2,626,624	...	...	808
Gibraltar	...	...	...	230
Italy	78,552	...	5,712	17,306
Malta	564	...	...	...
Ionian Islands	...	...	...	...
Turkey	32,457	...	...	...
Guernsey, Jersey, Al- derney, and Man ...}	13,516	2,464	6,076	9,537
Morocco	...	...	...	...
Western Coast of Africa	...	...	...	...
Cape of Good Hope	83,257	...	...	20
Mauritius	...	...	...	...
East Indies & St. Helena	...	...	...	3,656
New South Wales and Van Diemen's Land }	2,377,057	20	...	...
British N. Amer. Colonies	...	3,235	784	10,808
British West Indies	877	...	...	18
Foreign West Indies ...	...	...	...	...
United States of America	628,038	16,262	1,000	547,389
Brazil	15,456	...	...	...
Mexico	...	...	...	...
States of Rio de la Plata	56,689	...	...	1,899
Chili	...	...	...	...
Peru	...	...	...	...
Total	28,142,489	555,014	4,199,825	2,204,464

An Account of the Quantities of Manufactured Woollen Goods exported, distinguishing the Description of Goods in each Year, from 1820 to 1831, both inclusive.

Years.	Cloths of all Sorts.	Napped Coatings, Duffels, &c.	Kerseymeres.	Balizes of all sorts.	Stuffs, Woollen or Worsted.	Flannel.	Blankets, and Blanketing.	Carpet and Carpeting.	Woollens mixed with Cotton.	Hosiery.	Sundries unenumerated.	Declared Value.
	Pieces.	Pieces.	Pieces.	Pieces.	Pieces.	Yards.	Yards.	Yards.	Yards.	Dozens.	£.	£.
1820	288,700	59,644	78,944	37,183	828,901	2,569,105	1,288,409	526,124	407,716	59,960	39,337	5,586,138
1821	375,464	69,622	91,402	41,610	1,022,342	3,504,851	1,424,238	764,922	627,800	107,779	38,986	6,462,866
1822	420,497	67,757	95,870	43,447	1,078,428	4,503,612	1,926,711	884,922	1,120,326	136,597	47,042	6,488,167
1823	356,027	54,226	94,344	41,539	1,150,133	4,311,997	2,131,632	778,426	918,469	106,420	44,619	5,636,586
1824	407,720	51,585	108,012	47,105	1,242,403	3,105,961	1,990,041	848,842	1,393,443	113,123	43,361	6,043,051
1825	384,880	45,268	126,448	47,100	1,138,808	9,959,594	2,162,834	888,324	1,793,301	106,498	45,335	6,185,648
1826	328,559	41,800	86,038	36,862	1,125,308	2,423,120	1,082,582	903,597	531,517	71,922	37,223	4,966,879
1827	371,965	51,690	122,049	47,574	1,258,667	2,578,887	1,899,600	1,195,939	846,768	148,117	43,559	5,245,649
1828	335,042	40,646	84,524	49,567	1,310,853	2,539,766	2,097,542	1,197,947	981,152	159,463	48,314	5,069,741
1829	363,075	16,186	32,465	52,777	1,307,558	1,572,920	1,839,961	811,538	1,074,077	91,285	41,948	4,587,603
1830	388,269	22,377	34,714	49,164	1,252,512	1,613,099	2,176,391	627,869	1,099,518	111,146	54,038	4,728,666
1831	436,143	13,892	29,650	30,259	1,487,404	1,572,558	2,546,328	678,656	1,000,004	143,774	64,648	5,232,013

The declared exported Value for the present Year, 1836, is £6,460,144.

Manufac-
tures.

WOOLLEN MANUFACTURED GOODS.

Mechanical
Processes.

An Account of the Quantities of British Manufactured Woollen Goods exported, distinguishing the Description of Goods, and the various Countries whereto the same were exported, in the Years 1820, 1825, and 1831.

COUNTRIES TO WHICH EXPORTED.	1820.											
	Cloths of all Sorts.	Napped Coatings, Duffels, &c.	Kersey-meres.	Baizes of all Sorts.	Stuffs, Woollen or Worsted.	Flannel.	Blankets and Blanketing.	Carpets and Carpeting.	Woollens mixed with Cotton.	Hosiery.	Sundries Unenumerated.	Declared Value.
	Pieces.	Pieces.	Pieces.	Pieces.	Pieces.	Yards.	Yards.	Yards.	Yards.	Dozens.	£.	£.
Russia	9,807	908	9,035	1,472	71,252	80,039	12,270	43,901	31,669	460	2,072	346,331
Sweden	...	...	...	...	20	140	...	...	...	...	6	51
Norway	691	79	36	48	980	5,809	366	200	2,568	395	102	9,159
Denmark	96	10	144	...	1,441	3,277	680	302	255	197	51	5,227
Prussia	20	...	34	9	6,144	3,188	180	1,823	3,745	25	117	12,323
Germany	5,046	29,480	27,083	286	205,764	131,276	4,774	47,429	27,198	3,799	4,335	586,230
The Netherlands	6,234	15,231	3,119	2,106	36,084	125,937	18,796	39,866	130,706	14,371	2,469	254,712
France	16	...	...	...	...	92	600	865	2,169	34	303	1,309
Portugal, Azores, and Madeira	42,021	6,555	3,403	8,590	21,924	6,392	18,512	9,741	8,971	1,624	4,778	426,852
Spain and the Canaries	2,894	718	1,179	4,642	16,230	70,636	11,740	2,403	14,955	1,504	3,662	123,214
Gibraltar	4,129	315	2,804	1,358	11,827	48,596	2,300	3,454	17,281	1,430	2,832	98,913
Italy	23,108	3,333	2,526	166	30,864	22,719	6,389	23,649	9,965	326	426	200,947
Malta	600	...	125	1	1,451	2,720	160	1,400	489	37	1	11,686
Ionian Islands	...	...	12	6	167	...	...	200	...	...	30	554
Turkey and the Levant	233	...	82	2	3,629	3,635	...	3,880	...	3	40	12,871
Guernsey, Jersey, Alderney, & Man	3,175	11	6	12	1,043	7,157	3,140	9,108	15	873	106	38,209
East Indies and China	42,616	43	474	196	211,593	108,352	18,250	5,386	1,655	173	2,502	1,348,464
New Holland	538	3	43	15	512	5,128	6,640	470	1,769	69	155	10,043
Cape of Good Hope	918	465	875	589	3,660	20,590	12,460	685	6,250	265	663	37,151
Other Parts of Africa	181	12	...	2	678	1,784	1,250	1,200	180	84	395	4,630
British North-American Colonies	18,694	375	1,444	557	15,258	299,745	179,661	35,088	14,294	10,741	2,972	238,019
British West Indies	11,395	639	2,525	5,976	10,527	47,412	179,220	14,465	33,344	923	3,257	172,598
Foreign West Indies	4,385	114	1,134	1,189	2,681	25,283	192,500	3,145	3,659	100	493	75,752
United States of America	74,866	58	13,217	943	147,315	1,525,099	591,266	243,878	42,057	20,917	5,307	1,075,405
Brazil	27,977	988	6,948	7,246	18,909	5,114	25,395	3,169	24,526	215	1,403	342,044
Mexico and States of South America	9,060	307	2,696	1,772	8,941	18,985	1,860	30,417	29,996	1,395	860	153,444
Totals	288,700	59,644	78,944	37,183	828,901	2,569,105	1,288,409	526,124	407,716	59,960	39,337	5,586,138

COUNTRIES TO WHICH EXPORTED.	1825.											
	Cloths of all Sorts.	Napped Coatings, Duffels, &c.	Kersey-meres.	Baizes of all Sorts.	Stuffs, Woollen or Worsted.	Flannel.	Blankets and Blanketing.	Carpets and Carpeting.	Woollens mixed with Cotton.	Hosiery.	Sundries Unenumerated.	Declared Value.
	Pieces.	Pieces.	Pieces.	Pieces.	Pieces.	Yards.	Yards.	Yards.	Yards.	Dozens.	£.	£.
Russia	3,494	31	2,059	1	29,724	57,110	6,920	28,862	34,220	418	10	124,885
Sweden	15	...	...	...	5,201	126	1,840	3,048	820	29	...	8,309
Norway	1,101	140	138	77	1,033	5,346	1,144	725	857	150	130	8,930
Denmark	80	14	20	17	3,045	3,433	210	885	400	357	215	8,413
Prussia	...	...	10	...	852	1,249	200	250	900	37	30	1,504
Germany	1,433	13,822	58,370	562	332,086	134,944	3,678	38,078	11,992	2,489	3,150	576,641
The Netherlands	1,370	26,079	13,043	3,348	64,255	147,466	7,738	20,581	222,028	8,975	1,909	346,392
France	57	...	...	...	135	70	400	9,051	...	30	39	2,287
Portugal, Azores, and Madeira	46,578	1,523	2,479	4,965	29,538	42,859	20,092	17,990	52,650	1,145	4,556	360,398
Spain and the Canaries	1,146	59	145	1,432	16,391	28,062	1,475	3,170	20,880	1,347	628	54,313
Gibraltar	4,410	170	1,007	1,069	20,987	65,781	4,550	11,703	41,196	674	5,399	90,781
Italy	12,436	9	867	20	57,210	45,924	1,000	20,036	96,655	1,366	518	166,109
Malta	744	...	99	10	515	783	80	520	1,710	...	...	7,238
Ionian Islands	62	4	24	13	100	900	...	...	240	67	...	1,298
Turkey and the Levant	304	...	31	7	1,530	2,605	420	3,165	1,166	53	8	8,313
Guernsey, Jersey, Alderney, & Man	2,905	1,320	7	122	1,268	36,288	10,078	9,109	...	1,308	1,005	47,452
East Indies and China	44,960	4	1,158	1,383	184,818	50,687	17,524	15,612	12,692	488	5,060	898,737
New Holland	371	...	146	...	1,740	10,649	9,931	3,293	2,967	185	580	10,688
Cape of Good Hope	627	133	164	225	4,390	17,130	1,500	2,678	1,050	599	236	19,226
Other Parts of Africa	327	...	4	33	2,280	260	1,400	500	150	...	768	9,200
British North-American Colonies	25,620	1,242	2,111	400	30,022	542,607	240,990	70,534	45,990	17,820	6,848	310,190
British West Indies	10,667	268	1,009	6,008	11,446	66,551	125,657	10,256	145,434	1,015	3,152	139,112
Foreign West Indies	3,063	5	705	837	3,043	13,145	113,973	858	59,432	144	259	44,812
United States of America	135,809	319	24,789	13,248	264,401	1,595,233	1,480,937	543,753	447,617	60,753	7,625	1,959,689
Brazil	32,478	84	5,779	6,889	35,508	50,414	68,743	5,499	208,532	2,318	1,655	356,608
Mexico and States of South America	54,823	42	12,284	6,434	37,290	39,972	42,354	68,168	383,723	4,731	1,555	624,118
Totals	384,880	45,268	126,448	47,100	1,138,808	2,959,594	2,162,834	888,324	1,793,301	106,498	45,335	6,185,648

Manufac-
tures.

TABLE continued.

Mechanical
Processes.

COUNTRIES TO WHICH EXPORTED	1831.											
	Cloths of all Sorts.	Napped Coatings, Duffels,&c.	Kersey- meres.	Baizes of all Sorts.	Stuffs, Woollen or Worsted.	Flannel.	Blankets and Blanketing.	Carpets and Carpeting	Woollens mixed with Cotton.	Hosiery.	Sundries Unnume- rated.	Declared Value.
	Pieces.	Pieces.	Pieces.	Pieces.	Pieces.	Yards.	Yards.	Yards.	Yards.	Dozens.	£.	£.
Russia	6,800	86	2,093	76	22,741	83,875	9,250	11,425	7,770	231	223	101,686
Sweden	6	...	26	...	1,903	...	800	292	1,610	302	...	2,408
Norway	817	11	80	30	3,836	1,404	445	...	1,515	782	301	13,776
Denmark	38	...	98	...	957	10,237	200	254	160	288	123	2,674
Prussia	18	...	...	...	77	314	100	114	...	12	...	392
Germany	11,773	5,230	13,032	154	306,994	315,627	64,045	37,852	310,520	5,694	4,724	424,992
The Netherlands	2,854	7,805	1,543	6,239	71,571	214,821	38,850	12,310	126,794	17,187	3,822	200,205
France	250	...	134	13	4,637	8,316	5,600	2,446	8,637	332	17	11,513
Portugal, Azores, and Madeira....	24,150	179	874	8,104	21,193	10,942	11,890	4,628	33,782	779	2,660	161,128
Spain and the Canaries	4,455	26	665	1,018	43,035	24,009	3,400	5,980	42,120	990	886	109,375
Gibraltar	1,335	...	100	73	3,743	7,671	500	2,276	12,820	312	753	15,459
Italy	14,698	...	461	180	81,752	51,588	230	12,387	23,710	761	1,592	204,186
Malta	929	...	79	...	845	3,795	800	478	2,540	80	86	8,307
Ionian Islands	15	...	6	...	154	680	160	530	140	162	67	1,024
Turkey and the Levant	1,240	...	111	6	3,760	3,400	400	4,533	800	120	39	18,298
Guernsey, Jersey, Alderney, & Man	3,745	37	21	132	4,019	29,399	10,008	12,996	290	1,189	1,672	34,664
East Indies and China	69,969	4	102	342	165,680	64,912	24,440	5,562	21,920	1,141	1,972	671,902
New Holland	1,061	82	87	97	2,729	20,844	61,780	19,585	5,065	2,205	225	27,963
Cape of Good Hope	1,420	124	622	263	5,824	36,055	12,530	1,706	9,744	1,258	613	28,208
Other Parts of Africa	618	...	105	188	4,776	6,801	7,510	934	1,238	681	2,267	16,764
British North-American Colonies..	38,041	145	926	581	49,510	472,294	312,025	94,539	21,266	16,584	8,445	348,991
British West Indies	5,907	126	53	4,613	12,374	53,195	91,143	1,874	3,740	1,400	2,556	75,969
Foreign West Indies	4,158	11	44	51	5,927	1,620	56,110	610	16,412	235	836	42,561
United States of America	197,816	26	3,517	568	631,183	104,897	1,803,108	405,907	272,497	86,761	27,630	2,232,179
Brazil	7,514	...	858	4,326	11,477	22,957	14,139	973	33,254	155	888	83,335
Mexico and States of South America	36,516	...	4,013	3,205	26,707	22,905	16,865	38,465	42,160	4,183	2,251	394,054
Totals	436,143	13,892	29,650	30,259	1,487,404	1,572,558	2,546,328	678,656	1,000,004	143,774	64,648	5,232,013

Processes
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ture.

(1016.) *Processes in the woollen manufacture.*—In sketching the rise and progress of the woollen manufactures of this Country, our remarks have generally been made with reference to the impediments and encouragements which they have sustained and received from different Kings and Governors, their localities, &c., and nothing has been said with respect to alterations and improvements in the manipulations and mechanical means by which they were conducted. Indeed, from the earliest period of those manufactures to the latter end of the last century, very few, if any, mechanical improvements had taken place; the only change, where any took place, being in the increased skill and dexterity of the operator, and in a choice of materials better suited for particular purposes. The carding and spinning wool for cloth, and the combing, spinning, &c. for worsted yarn, as also the processes for dyeing and dressing of cloth, in the early part of the reign of George III., were effected by the same means as in the time of Edward III., which probably were similar to those of the ancient Romans, except that perhaps the earlier machines were somewhat more rude in their construction. In an Art which had for so many centuries rolled on without any change, it did not appear possible to the manufacturer that any improvement could be effected; and had not the genius of Hargreaves and Arkwright changed entirely the modes of carding and spinning cotton, the woollen manufacture would probably have remained at this day what it was in the earliest stages of civilized Society. Some writers, amongst whom we may men-

tion the author of the article *Woollen Manufactures*, in Rees's *Cyclopædia*, to whom we are indebted for several particulars, are of opinion that it would have been better for mankind had they so remained, a doctrine, however, to which we cannot subscribe. At all events, it was impossible, after the invention of the spinning jenny, and the water frame or roller spinning, that the woollen yarn should still be a mere hand operation on a single thread at a time.

The spinning jenny for woollen yarn, which was precisely similar, but somewhat larger, than that employed in the cotton manufacture, was first introduced into Yorkshire in 1780, but did not become general till about three years afterwards. In the first jennies not more than eighteen or twenty threads could be spun, and the mode of winding the thread upon the spindle was very imperfect. The carding was still effected by hand, and the slubbing or roving was prepared on the common spinning wheel. For some time considerable difficulty was experienced in the carding machinery, particularly in clearing the wool from the card, and a slight change in the form of the machine was found necessary to prepare the wool for the slubbing billy. Soon after this, the carding and spinning woollen yarn became general through the manufacturing district of the West Riding of Yorkshire; a large mill was erected in which the carding and scribbling machines were turned by water wheels, and the roving or slubbing performed on the billy. The wool carded at these mills was sent to the smaller manufacturers in the state of slubbing, and the

Manufac-
tures.

further process of spinning was conducted by these persons with jennies on their own premises. Before the year 1790, the old processes of carding by hand and spinning on the wheel were entirely discontinued in Yorkshire; but it was some years after before the new processes were generally introduced into the West of England. Soon after this period the steam-engine, which had then only recently been employed for propelling machinery, was introduced into Yorkshire for the purposes to which the water wheel had been applied, and it is now commonly used in the principal woollen manufactories. We now proceed to describe the several processes.

Wool mill
or devil.

(1017.) *Wool mill, called also a devil.*—This is differently constructed in different manufactories, but the most common form consists of a cylindrical drum, about three feet long and two and a half feet in diameter, furnished with teeth or spikes throughout its surface or circumference; this turns on an axis fixed in a strong wooden frame enclosed on all sides, but the ends of the case turning on hinges which allow them to be let down; the lower part is not, however, close boarded, but splinted, so as to admit any dirt, extracted by the operation, to fall through. On the axle of this drum is a wheel, and over the cylinder within the case are five smaller rollers or cylinders, also covered with teeth, and turning on axes fixed in the frame. The teeth of the rollers and those of the drum or cylinder intersect each other during the rotation, as do also the teeth of the rollers themselves; motion is given to the whole by a fast and loose pulley, or other contrivance, to connect the machine with the first mover. The front door is now turned down on its hinges, and a quantity of raw wool, as it is received from the wool stapler, is laid upon it; the door is then closed, by which means the wool is brought within reach of the teeth of the drum or central cylinder, which carries it upwards so as to work it between its own teeth and those of the upper rollers. The motion of the cylinder is very rapid, and as the wool is drawn from tooth to tooth, it is opened and the longer fibres broken; after a certain number of revolutions, a door, similar to the one last described, is opened at the other end of the machine, and the wool is thrown out by the centrifugal force of the cylinder; it is then again closed, the former one opened and supplied with another charge of wool, which is in like manner ejected, and so on with fresh charges, each being about a pound in weight.

This operation is sometimes repeated several times; when the dye is given to the wool, it is repeated after dyeing; it is employed also for mixing different wools together.

Scribbling
machine.

(1018.) *Scribbling machine.*—This machine resembles in some measure that last described, consisting of one large central cylinder with smaller ones in pairs, called workers and clearers, which, however, are covered on their surfaces with cards instead of the strong teeth, and the wool is supplied by a feeding apparatus, after the manner explained under carding, in the cotton manufacture. The centre cylinder is turned rapidly by means of its connection with the first mover, and the wool is scribbled or carded in its passage between the teeth of the cards on the cylinder and rollers, which do not, however, in this machine, intersect each other, but are brought so near that the fibres of the wool which the teeth of one card contains are caught by the teeth of the other card, and drawn out a few at a time. This separates the fibres and makes

the wool light and open, and also distributes it with great evenness over the surface of the cylinders. After it has passed between three or four pairs of workers and clearers, (the former being the denomination of the small rollers which take the wool from the great cylinder, and the latter that which take it from the worker,) it is taken up by another cylinder called the doffer, from which it is stripped off by a comb, precisely as we have described in the carding machine in the cotton manufacture, (Art. 990.) except that it falls in a continuous fleece instead of being condensed into the form of a roving. This operation is repeated two or three times, till it is at length reduced to a proper state for carding. In several manufactories, however, a double scribbling machine is employed, when sometimes one operation suffices, but it is commonly afterwards passed through a single machine; in this double machine the second great cylinder receives its wool from the doffer of the former, and one comb only is therefore necessary.

(1019.) *Carding machine.*—This is framed on nearly the same principle as the scribbling machine, except that the doffer is not entirely covered with teeth, but with strips of cards about four inches in breadth, and which are therefore stripped off from the doffer in very delicate films or webs of that breadth, and about twenty-seven or twenty-eight inches in length, i. e. of the length of the doffer. These are rendered cylindrical by falling into a concave semi-cylindrical shell or case, in which a fluted cylinder revolves, and which gives to these films of wool a cylindrical figure, which is the first element of the thread; when they arrive at the further side of the above cylindrical shell, they fall out in their condensed form upon an endless cloth stretched over two rollers or cylinders; this is continually revolving, and as each sliver arrives at the edge of the cloth it is removed to the next machine, which is called in the cloth manufacture a slubbing billy, differing only in degree from the roving billy in the cotton manufacture; the several slivers are laid in succession on a feeding cloth, and their ends slightly combined by boys or girls employed for the purpose.

(1020.) In the *slubbing billy*, the thread first becomes continuous, and is in this state called, in cloth-works, billy. a slubbing, corresponding to what is denominated a roving in the cotton; and all its subsequent processes differ so little from those which have been described in cotton roving, spinning, &c., as to render it quite unnecessary to enter into particulars. It will easily be imagined that two textures differing so much as wool and cotton require some differences in the proportions of the different parts of the machines, and in the degree of speed with which the machinery is driven; but these are minutiae which would scarcely be distinguished were we to give separate drawings of the machines, we refer, therefore, to roving and spinning in the article COTTON MANUFACTURE. The next steps of course, after the thread or yarn has been properly formed, is that of warping and weaving, which we propose to describe generally for various goods under the article WEAVING. We shall, therefore, now consider the material as manufactured into cloth, and endeavour to illustrate the subsequent operations which it has then to undergo before it is considered in a fit state for the general market.

(1021.) *Processes subsequent to weaving.*—It is essential to the manufacture of cloth that a certain quantity of Fulling, &c. milling, &c.

Manufac-
tures.

oil should be employed, and therefore the piece as received from the hands of the weaver is not in a state for immediate use; it is greasy and rough, and has to undergo several operations before it acquires that smooth and level surface which is at length given even to cloths of very common quality. The first step to be taken is that of scouring; this is effected by first soaking the cloth for some hours in alkaline mixtures, and afterwards in clear water; this neutralizes the grease and allows of its more easy removal. In this state it is taken to the fulling mill, and worked with the heads of the stocks, as described under FULLING MILL. (Art. 501.) This process being completed, it is taken to the *tenter field* and stretched on tenter frames. These consist of a number of vertical posts fixed in the ground, with a continuous horizontal fixed rail at top as long as the piece of cloth; there are also other horizontal rails which are fitted between the upright posts, so as to slide freely up and down, and can be fixed at any distance beneath the upper rails by means of holes and pins, according to the width of the piece of cloth; both the upper and lower rails are driven full of tenterhooks; on these the lists of the cloth are fastened, after which the lower or movable rail is pressed downwards to the full breadth of the cloth, and then secured in its place by the pins above mentioned. In this state the pieces are left to dry; they are then removed and minutely examined in every part, and all knots and uneven parts removed, and any rents or defects which can be found are repaired by introducing fresh threads with a needle; this operation is, in the language of the manufacturer, called *burling*.

Milling
and felting.

The next process is that of *milling* or *felting* the cloth. In the state in which cloth is received from the tenter field the naked threads are very perceptible, and the subsequent operation of milling is to swell the threads, and felt them so as to allow of the cloth afterwards receiving that fine, smooth, and polished surface which is the great beauty of fine cloth, and which renders it also more impervious to wet. Commonly, a piece of cloth of sixty-two yards requires six pounds of soap, which is dissolved in water, and about a handful spread upon each yard in length; the piece is then put into a trough and worked for three hours in the fulling mill, during which the cloth is frequently moved as described. (Art. 502.) The blows upon the cloth cause a motion of the fibres of the wool amongst each other which is facilitated by the soap; by this means the mixing, entangling, and matting of the fibres is produced, constituting the felting.

After the three hours' milling, the cloth is taken out of the trough and again soaped, and is then returned for three hours more. This is repeated four times, making twelve hours' milling in the whole, and then a stream of clear water is admitted into the trough to wash away the soap. The piece of cloth is commonly, at the conclusion of this operation, reduced in breadth about two-fifths, and in length one-third. It is now again stretched on the tenter frame, in which it is extended in length about one-twentieth, or two yards in forty; but it is not stretched in breadth, or very little. The cloth remains in the open air till it is quite dry and ready for the final operations of dressing and shearing.

Dressing.

(1022.) *Dressing*.—In this process the nap of the cloth is raised, by the action of what are called *teasles*, a species of thistles, to its surface. These are cultivated in different parts of England, and supplied to our clothiers

for the purpose; they are hard balls covered with scales terminating in strong stiff points, which turn downward like hooks and are very elastic. Formerly a number of these were arranged in frames so as to form a kind of hand card; and the dressing was performed by two men who held the teasle frame by its handle, and worked the cloth with it, the cloth itself having been hung up in a vertical position; when one part was finished another part was brought forward, and so on till the work was completed; and this was repeated three times, the cloth being wetted, and then three times after being dried. This hand process, however, is now almost or entirely discontinued, and the dressing is effected by machinery, and in some cases fine wire cards are made to supply the place of the teasles; this machine is denominated a *gig mill*.

(1023.) The *gig mill*, like most other machinery connected with manufactures generally, and that of cloth in particular, varies considerably in form in different manufactories. In that represented in plate lxxii. fig. 1, *Pl. lxxii. Fig. 1.* F F, &c. are frames of teasles ranged round a large central frame constituting a sort of drum, which receives its motion from a strap over the pulley D, which, by the wheelwork shown in the figure, gives motion to the drum and to the upper and lower rollers. The piece of cloth is wound tightly and smoothly upon the lower beam, as it passes thence to the upper beam; jets of water are also supplied from the horizontal pipe N, to give a proper degree of moisture. The machine being now put in motion, the working of the surface of the cloth is effected by the rotation of the teasle drum; and the upper beam, whose motion is properly regulated by the wheel gear, is made to receive the cloth at precisely the speed with which it is delivered from below. The first operation being completed, the rollers are made to change place, and the operation is then repeated as often as requisite.

(1024.) *Shearing*.—The nap having been sufficiently raised by the foregoing operation, we arrive at the final process of shearing. It will be obvious that the wool raised by the teasles will cover the surface of the cloth after the manner of a loose fur, which must now be removed by proper means; this is called shearing or cropping.

This was formerly, and is at this time, frequently performed by hand. The clothier's shears consists of two very large blades of steel united together by a steel stem which is bent into a bow, but is sufficiently flexible to allow one of the blades to be moved upon the other in order to make them cut; both blades are ground to sharp and straight edges, which apply one to the other, but they are not in parallel planes like those of a pair of scissors, but inclined at an angle of about forty-five degrees; that is, one of the blades being laid flat upon the cloth, the other will then be inclined to the cloth at the above angle. The cutting edge of this inclined blade bears upon the surface of the flat blade, and the spring of the blade is so set as to press the two edges always together. The lines of the edges of the two blades are not parallel to each other, but so inclined that the edge of the upper blade crosses the edge of the lower, and bears upon its flat surface at the end nearest to the bow, whilst the other end of the edge of the upper blade is removed over the edge of the lower, thus leaving an interval between the two edges when the shears are open. In this state, the shears being opened, if the lower blade be laid flat upon the surface of the cloth, the nap or wool which is to be removed by

Mechanical
Processes.

Gig mill.

Pl. lxxii.
Fig. 1.

Shearing
by hand.

Manufac-
tures.

the cropping will stand up above the edge of the lower blade, in the interval between the two edges, then, if the blades be forced together, the edge of the upper blade will pass or cross over that of the lower, and cut away all the wool which projects above the edge of the lower blade. The contact of the cutting edges begins at the end nearest to the bow and proceeds regularly to the other, in consequence of the two edges not being parallel as above explained. The blades open or return to their former position by the elasticity of the bow, and in order to make the cut they are closed by means of a handle or lever, which is fitted or lodged on a round part of the stem of the bow, so as to play thereon as upon a centre of motion. A double cord is made fast to this lever or handle near to the centre, the other end of the cord is fastened to a block of wood which is screwed to the flat of the lower blade, and rises up to a proper height; by depressing this handle the shears are closed, and make their cut with the greatest facility, when, as already described, the elasticity of the bow returns the blade and handle to their original position.

The operation is as follows. The piece of cloth is laid down in folds upon a plank or low bench placed on the ground, and the end is drawn across a table or bench which is covered with cloth and stuffed with horse hair, forming a large flat cushion. The cloth is stretched out flat upon the surface of the table, and is retained by hooks and weights. Two workmen are employed to shear a piece of cloth; they place the lower blades of their shears flat on the surface of the cloth, with the line of the edge in the direction of the length of the piece; one of the shears is laid on the edge or list of the cloth, and the other exactly in the middle of the breadth of the cloth. The bows and stems of the shears project over the edge of the table, and the workmen place themselves at that edge; each man guides the shears with his left hand, and makes the cut with his right; a short staff is lashed to the bow of the shears to hold them by, and secured by a stay to the lower blade; its direction is nearly parallel to the back edge of the upper blade. The workman puts his arm through the bow as far as the elbow joint, then lays the fore arm flat against the staff, which he grasps with the hand; and in this way he has a great command of the shears, leaving the right hand at liberty to work the handle which closes the shears. This handle is moved backwards and forwards with great rapidity, to make cuts or clips on the cloth, and between every cut the lower blade is moved a small space on the cloth to cut in a fresh part.

The art of shearing consists in moving the shears with great regularity and parallelism, so that every part of the surface shall be equally cropped. The closeness with which the shears cut is regulated by weights laid upon the flat of the lower blade; these press the blade down into the soft cushion on which the cloth is spread, so that the fur will stand up more above the edge of the blade.

(1025.) *Shearing or cropping machines* have now very commonly superseded the hand shearing, but they are so variable in their construction and action, that it is impossible to give any minute description. The first attempt was that of the shearing frame, which was merely a contrivance to work similar shears to those we have described by machinery instead of the hands of the workman. At the side of the table or cushion on which the cloth is spread a long stool is placed having

grooves at the edges to guide the wheels of a carriage on which the shears are fixed by their bows. There is a carriage for each pair of shears, and they are smoothly and slowly moved along the stool by a cord which winds upon a roller turned by wheelwork, and at the same time the handles of the shears are continually pulled by a cord connected with a small crank which turns very rapidly; the direction of the cut is lengthwise of the piece of cloth, and the two pairs of shears advance across the breadth until the whole is cut; the machine is then stopped, the shears removed, and the piece of cloth shifted upon the table, and a similar process repeated, and so on. This method is still practised in many manufactories, but the perpetually shearing or cropping engines are generally superseding all other methods. Of these we have still many varieties, but we must confine our description to one only; and we select that of Mr. Price, of Stroud, in Gloucestershire, which is explained at large in vol. xxix. of the *Repertory of Arts*. This machine shears or crops the cloth across the breadth, beginning at one end of the piece and continuing regularly to the other. For this purpose the cloth is conducted through the machine by the motion of rollers, and is drawn over a bed or support which lies beneath the fixed blade of the shears, (which answers to what is called the ledger blade in the common shears,) so that the cloth passes between the bed and the stationary blade.

The moving blades of the shears are fixed on the circumference of a cylinder situated above the fixed blade, with its axis exactly parallel thereto, and capable of revolving by the power of machinery, so that the edges of the moving blades will be carried against and passed over the edge of the fixed blade, in order to cut away all the wool of the cloth which rises above the edge of the fixed blade. Several such moving blades are fixed upon the same cylinder to act in succession against the fixed blade, and these moving blades are placed obliquely to the axis of the cylinder, or in such a manner as to form portions of spirals; but as all parts of the cutting edges are equidistant from the axis of the cylinder, it is manifest that, in the revolution of the cylinder, every part of each spiral edge is brought in succession into contact with the fixed blade, so that in its revolution it crops off all the wool which, by the progressive motion of the cloth over its bed, is raised up against the fixed edge. The edges of the moving blades are placed at such a degree of obliquity to the axis of the cylinder, that, at the same instant the end of one ceases to cut against the edge of the fixed blade, the following revolving blade will begin its action at the other end of the cylinder; therefore, by the time that any one of the revolving edges has passed over and made its cut against the whole length of the fixed blade, and is ready to quit it, the succeeding revolving edge is brought into action, and when this has passed, the next in succession begins, so as to keep up a continued action.

The cloth is stretched in width by a contrivance which Mr. Price calls stretching bands, to prevent it getting into folds or wrinkles, which would be injured by the shears, or make irregularities in the shearing. These stretching bands are endless straps or bands, each of which is extended over two wheels. The bands have sharp pins projecting from them into the lists at the edges of the cloth, and being so situated that one of them lies exactly beneath each list, they are

Mechanical
Processes.

Shearing
by ma-
chinery.

Manufac-
tures.

caused to circulate round their respective wheels by the motion of the cloth. The stretching of the cloth is effected by the position of the wheels on which the bands circulate, the direction of the bands being slightly oblique to the lengthways of the cloth. The endless straps are so fitted into grooves or troughs, that they are firmly retained to move straight forwards in their oblique direction; and the direction of the obliquity is such, that the bands are nearest together at that end where their pins take hold of the lists of the cloth; but as the bands move forwards with the cloth they recede from each other, and extend the cloth in breadth in consequence of their obliquity, which may be decreased or diminished as is found necessary. The actual width between the two bands is also to be regulated according to the width of the piece of cloth. It is not usual to crop the lists of the cloth; and, indeed, as the lists are usually of thicker substance than the other part of the cloth, they would bear up the fixed blade too high from the cloth to cut the nap quite close; for this reason, the bed or support on which the cloth is cut is so constructed that it can be adapted in length to the breadth of the piece of cloth between the lists, in order that the cloth only may be supported or borne up to the edge of the fixed blade, whilst the lists, being depressed or borne down below the level of the bed, (by thin slips of metal called guards,) will escape the action of cropping, and thereby remain with the long wool upon their surfaces. The bed by which the cloth is borne whilst it is cut is only a narrow ridge of metal, over which it passes so as to be bent with a sudden curvature, and in this way the nap can be cut more close and even than upon a flat bed or soft cushion. The operation of cutting is facilitated by a row of pieces of metal screwed to a strong bar to form a straight edge, very similar to the cutting edge of the fixed blade, but thin and elastic; this edge is placed close to the elevated ridge of the bed, and presses the cloth gently down upon the bed immediately before it comes to the edge of the fixed blade, against which the nap is to be cut off; this elastic edge being placed on one side of the ridge, and the cutting edge of the lower blade on the other side, the cloth is only exposed for a very narrow space just where it comes to the cutting edge. By this means the cloth can with safety be brought nearer to a level with the upper surface of the fixed blade, so as to shear it closer than could otherwise be done without endangering the cloth.

The ends of the ridge part of the bed are composed of a number of narrow plates of metal accurately fitted together, and placed side by side in a mortise made in the end of the solid bed; their upper ends project out from the mortise so as to line with the elevated ridge and form a continuation thereof, but there is a sliding piece in the bottom of the mortise on which they all bear, and the point of it is of a wedge form. By removing this wedge, any number of the movable pieces may be let down, so as to diminish the length of the elevated part of the bed at pleasure, according to the breadth of the cloth. The whole of this machine is very well contrived to effect the desired object: it will be found fully described, with drawings, in the *Repertory of Arts*, vol. xxix.; see also vol. xviii., lviii., lx., and many others, on the subjects of dressing, cropping, &c. The goods in this state require only to be brushed, pressed, and packed to fit them for the general market.

Worsted
manufac-
ture.

(1026.) *Worsted manufacture*.—We have said all that is necessary relative to the history of the worsted manu-

facture, in our general sketch of that of the woollen Mechanical Processes. manufacture, of which, indeed, the worsted is only a particular, although a very extensive, branch, the original material in both cases being the same. The principal difference is that, in what is commonly called woollen cloths, a nap or pile is raised so as to hide the threads of which it is composed, whereas in worsted stuffs, there being no pile, the threads are exposed. In the former, also, the shorter wool is employed and the longer fibres broken down by the wool mill and carding machine, whereas in this, long wools are preferred and the shorter fibres rejected. Moreover, the yarn is doubled and twisted much harder, and what little floss or woolliness may appear on its surface is frequently removed by singeing. The first operation in the worsted manufacture is that of combing, which was formerly wholly performed by hand, and is so still to a considerable extent, although some successful attempts have been recently made to effect this by machinery.

(1027.) *Wool-combing by hand*.—The wool being first washed in soap and water to cleanse it from the dirt and other impurities, it is drained from all superfluous moisture and thrown lightly into a basket. It is then separated by the comber into handfulls of about four ounces each, which he sprinkles with oil and rolls in his hands to distribute the oil uniformly.

This he transfers to his comb, which is a sort of hackle, resembling in some measure the hackle represented in flax manufacture. A pair of combs is represented in pl. lxxii. fig. 2; each is composed of two rows of teeth of well-tempered pointed steel disposed in two parallel planes, one row being longer than the other. These are fixed to a wooden stock or head which is covered with horn, and to this head is attached a wooden handle. Each workman has two of these combs, and as it is essential to this process that the teeth should have a certain heat to produce the best effect, it is necessary also that he should be provided with a comb pot, commonly containing a charcoal fire for heating the teeth. The comb pot generally contains eight openings for inserting the combs, so that one is sufficient for four workmen. See fig. 3. The only other essential part is a post or pillar, fig. 4, to which either comb may be attached for drawing the sliver.

The teeth of the comb being heated, it is fixed to the pillar above mentioned, with its teeth uppermost, and is then filled with wool. The workman, taking about half a handfull, catches it upon the teeth of the fixed comb, and by drawing the wool towards him, and at the same time downwards, a portion of the wool is left; and this is repeated till all the wool is gathered upon the teeth. The comb thus filled is placed with its teeth in the stove or pot, the wool being outside, the other comb is then filled in the same way and placed in the pot to be heated. Both combs being thus filled and heated, the comber holds one of them in his left hand over his knee as he is seated on a low stool, and with the other comb in his right hand he combs the wool upon the first by introducing the points of the teeth of one comb into the wool contained in the other, and drawing them through it until the fibres of the wool are disentangled and laid parallel. During the working, he frequently changes the combs hand for hand; but as the wool will accumulate upon that comb which is most worked, he manages so that, at the end of about five and thirty or forty strokes, nearly all the wool will be gathered upon one of the combs and hang down

Wool-
combing by
hand.

Pl. lxxii.
Fig. 2, 3, 4.

Manufactures.

from its teeth in a fair lock of straight and regular wool. This comb is then put to heat for a short time; he then fixes it to the post and proceeds to draw the wool from the comb in a sliver. This is done by his taking hold of the projecting wool with the fingers and thumbs of both hands, and drawing it away from the teeth in a direction perpendicular to their plane without sliding it off their points, and as the wool comes away seizing it again near the teeth, and so on. This being done, a portion of short wool will not come off, as he never seizes hold but at a certain distance from the teeth; this, therefore, remaining after the sliver is drawn is removed; it is unfit for worsted spinning, and is therefore collected under the name of noil, to be applied for other purposes. The wool thus drawn from the comb forms a long sliver, the fibres of which are straight and parallel, but not sufficiently so for spinning, the process is therefore repeated a second and sometimes a third time.

Wool-combing by machinery.

(1028.) *Combing by machinery.*—The first attempt of this kind was made by Mr. Cartwright, in 1790; but since that time there have been many, the greater number of which, however, were failures, either from a want of perfection or a want of encouragement; of these we may mention Wright and Hawksley's Patent in 1793, and another of the same date by Mr. Toplis. In 1797, another Patent was taken out by Hawksley. Mr. Arnatt and Mr. Pearce also took out Patents for wool-combing by machinery, the former in 1795, and the latter in 1798; since which time Mr. Gilpin and several others have produced machines for this purpose, some of which are now employed, and a considerable quantity of wool is at this day combed by machinery. Mr. Gilpin's machine consists of two wheels, each carrying four combs at equal distances, so placed that, as the wheels pass each other in their rotation in opposite directions, the teeth of the opposite combs meet each other. The combs are so made that they can be readily removed from the wheels or frames, and be as readily replaced, and can therefore be heated the same as hand combs; the wool is also filled upon the combs by hand, and the combs and wool heated in the usual manner before they are put into the machine.

Mr. Gilpin's machine.

One of these comb frames is simply turned upon its axis by the first mover of the mill; but the other has a compound motion given to it by means of machinery, so that while it revolves on its own axis, this axis advances and recedes from the other frame with a motion parallel to itself, which is repeated four times every revolution. The advancing motion is gradual and limited to a certain extent, but at the same time there is a third movement which regulates this extent, so that every succeeding stroke the two frames will approach nearer to each other, and the returning or receding motion is made with three times the speed of the advancing or forward motion. This is effected by the circular motion of the frames being driven by an elliptical wheel, which occasions them to move alternately quicker and slower, according as the second wheel is advancing or drawing. In this way they continue to make successive strokes till the wool is sufficiently combed, the machine is then stopped, and the combs taken off one by one, to be replaced by others, which are filled with fresh wool and properly heated. There is, however, another motion in the wheel, which we have described as turning on a fixed axis, which has not yet been mentioned; the axis of that wheel has a slow

Mechanical Processes.

motion backwards and forwards endwise, in the direction of its length, for a short distance. The intention of this is that the same parts of the combs shall never come opposite to each other at two successive strokes.

It should be observed that, when the machine is first set to work, the combs at their point of meeting do not come within three or four inches of each other, and the points only penetrate amongst the longest fibres of the wool upon the combs; but at every stroke which is made, the combs advance nearer together, and take deeper into the wool, until after a certain number of strokes are made the combs approach as near as they can without touching. They continue to work in this manner for some time, and when the intended number of strokes is made a bell rings, as an indication that the machine should be stopped. This is done by drawing a lever, and in consequence the machine will stop itself in the exact position for changing one of the combs on each frame. These are removed, and others, ready filled with wool and heated, are put on in their places, which, being done on both frames at the same time by two persons, is only the work of a moment. The machine is then put in motion, but by the machinery it will stop itself again at the required position for changing the next pair of combs; it is then put forwards, and so on, until all the eight combs are changed.

The combs which are removed from the machine are put into the stove to heat for a few moments, and then the wool is drawn off from them by a separate machine. The head of the frame or reel is here placed in a perpendicular groove, so that its teeth stand horizontal; and a piece of metal, which is fixed to the head of the comb, and projects therefrom like a tooth, enters into the spiral groove of a screw, which stands in a perpendicular position, and is continually turned round by the machinery. By this means the comb is regularly and slowly let down in the groove from top to bottom. A pair of fluted rollers is placed horizontally and parallel to the teeth of the comb, in such a position that the comb, in descending, will pass with its teeth at a proper distance from them, to draw off the wool in a sliver; after passing through these fluted rollers, the sliver is conducted through a perpendicular revolving tube, which gives a roundness to it, the same as it would acquire by being rolled between the hands, and then it is conducted between a pair of plain rollers, which deliver it into a tin can placed before the machine.

A wooden roller is placed above the fluted rollers, with eight pieces of board projecting from it in the direction of radii; when the roller turns round, these boards act to stroke the wool upon the comb and raise it into a proper situation to be drawn off by the fluted rollers. The combs are prepared for drawing off the wool by heating them, as before mentioned, and by sliding the wool from the roots of the teeth halfway towards their points; in this state the combs are carried one by one to the drawing-off machine, and the head of one comb is put into the top of the perpendicular groove by the projecting tooth, which enters the spiral groove of the perpendicular screw. The wool is now gathered up and introduced between the fluted rollers, the machine is put in motion, and by means of the screw the comb is gradually lower down, and the wool is drawn off from it in a sliver, which is rolled up into a compact form by the revolving tube, through which it passes, and is delivered into the can by the plain

Manufac-
tures.

rollers; the attendant holds another comb ready to follow the first, and when it has descended to a certain point, he slips the next comb into the perpendicular groove, so that it rests upon the former, and the wool upon the two combs joins as it were in one. The stroker, when they pass before it, lays the fibres all one way, and the wool is drawn off by the rollers in a continued sliver, which does not present the slightest appearance of joinings; another comb is then put in, and the wool joins to the former, and so on. The backings, or wool at the back of the combs, are drawn off by the boy stationed at the back of the machine; and the combs, as they come through below, are received by boys, who afterwards take away the noil or short wool which remains in the teeth, and then put the combs back into the stove to heat them, ready to be filled again, in order to proceed with another combing. When the wool of all the eight combs is drawn off, the motion of the drawing-off machine is stopped at the moment when the eighth or last comb has descended half way through its course. In this state the machine waits till another combing is finished, and then the succeeding comb being placed on the top of that one which continues in the machine, the continuity of the sliver will be preserved.

The inventor of this machine states in his specification, that for common work the wool only requires to be operated upon once by the combing machine; and in that case, the machine must be adapted to make twenty-four strokes of eight pair of combs before the bell rings. For medium work, such as would require to be combed twice over in the usual manner of hand-combing, it must be combed twice over by the machine; thus, after having been combed once in the manner described, the sliver of wool is broken up into handfulls, and filled on the combs again by hand as before, and combed over again in a similar manner, but the combs are less heated for the second time of combing. By changing a wheel, the machine may be adapted to make only fourteen or sixteen strokes before it stops, when it is intended to comb twice over. The wool intended for the finest spinning should be combed three times over, and the machine should be set to make fourteen or sixteen strokes for each pair of combs. The machine has also two different movements for the drawing out of the movable comb reel; in one, the motion is over a space of ten inches, and is adapted to comb wool having six or eight inches length of staple, and is called wether wool; but by a slight alteration, the excursion of the movable reel can be increased to thirteen inches, and is then adapted to comb wool which has from eight to eleven inches length of staple.

Mr. Gilpin's machine has the advantage of heating the combs and of filling them by hand, both of which are essential to any machine which is proposed to comb the raw wool. The filling is an operation which requires discretion, if it is to be expected that the long fibres shall be preserved without breaking. The person who fills the wool on the teeth takes a greater or less lock of wool in his hand, according to the condition of it and the degree of entanglement; also in drawing it between the comb teeth, the force is proportioned to what the wool will bear. Mr. Gilpin's specification states that, under certain circumstances, when the wool will not wash well, but remains taggy, it is advisable to fill it upon the combs and slip it off, then fill it again preparatory for the machine. As the object of this first

filling is chiefly to warm the wool, the end may be in part attained by laying the wool upon the top of the stove for a few minutes before it is filled.

As we believe that the combing machines which are at present in operation, and which are not very generally shown, differ in many respects from that above described, and as we have not had an opportunity of witnessing the operation except in one case, which nearly resembled the above, we shall proceed without describing processes, which, however ingenious, are not in use, to illustrate the subsequent operations of breaking, drawing, &c., as far as they differ essentially from those described under the articles cotton and flax manufacture.

We have seen that the wool which is combed by hand is left in slivers varying from five to seven feet, but that combed by machinery is produced in one long continuous sliver; the former has therefore to undergo one process more than the other before the first continuous thread is formed: this is called planking. The slivers are rolled up by hand by the wool-combers in balls or tops, each containing ten or twelve slivers, and weighing about half a pound. These are unrolled and the slivers laid on a long plank or trough, with the ends overlapping, in order to splice the long end of one sliver with the short end of another. The long end of the sliver is that first drawn from the comb and contains the longest fibres, and the short end that which comes off last from the comb, containing therefore the shorter fibres. These ends are distinguished by the wool-comber, and the slivers are accordingly arranged by the woman or boy attendant as above described.

(1029.) *Breaking machine.*—The planking table is a part of what is called the breaking machine, represented at E, in fig. 7. Here the slivers are planked or spliced together, and are immediately drawn out and extended by the rollers of the frame, as represented in the figure.

The lower roller of the first pair of rollers receives its motion from the mill, and the roller immediately above is borne down upon it by a weight; as the motion proceeds the sliver is compressed, and is passed through the second, third, and fourth pair of rollers, which, moving with different velocities, draw out the fibres on principles very similar to those already described in the preceding articles on roller spinning, and the sliver is ultimately received into a can, as represented at C. The frame carrying the third and fourth pair of rollers is adjustable by the screw *f* to different distances, according to the staple of the wool.

The breaking and drawing frames, which are used when the slivers are prepared by combing machines, are differently constructed; these have no planking table, but receive three of the perpetual slivers from as many tin cans, or from large bobbins.

(1030.) A machine of this kind is represented in plate lxxii. fig. 5, 6, being according to a Patent taken by Mr. Lister in 1823; in which fig. 5 is a side elevation of a drawing or roving frame; B, B, B are three bobbins mounted in the usual way, each containing slivers of wool; R is a small roller partly immersed in a shallow cistern, W, of hot or cold water; P, P are two plain rollers, the upper one resting and rolling on the lower; and in order to cause a pressure between these two, a weight is hung upon the axis of the upper one. It follows from this arrangement that if the slivers S, S, S, on the bobbins B, are drawn under the roller R, they will pass through the water in the cistern W, and be thus wetted. If the

Mechanical
Processes.

Planking
hand-combed
wool.

Breaking
frame.
Pl. lxxii.
Fig. 7.

Mr. Lister's
patent
drawing
frame.
Fig. 5, 6.

Manufac-
tures.

slivers are then drawn between the rollers P, P, a weight being hung on the axis of the upper one, the greater part of the water will be pressed out of the slivers; D, C, C, D are the carrying rollers. If the slivers, after leaving the rollers P, P, are then passed between the drawing and carrying rollers, they will arrive at the cylinders K, K, &c., the two lower of which are hollow; these are called the calendering rollers, the two upper of which are also pressed upon the lower ones by weights on their axes. The surface of these rollers are perfectly smooth and true, and the under ones being hollow may be heated by steam or otherwise, so that in the passing of the sliver between them it is calendered or hot-pressed, so as to take from the fibres any curl or frizzle; they then pass to the top of the spindle Q, and are twisted in the usual way, which is seen in the drawing, the front post of the machine being broken off to exhibit it. Mr. Lister's specification then particularizes as follows. The first motion is given to the machinery in the usual way, by means of the pulley V, over which a band is passed communicating with a competent power. On the same axis with the pulley V is a long drum M, over which bands pass to communicate motion to the revolving spindles Q, and also a pulley X, which communicates motion by means of a band to the pulley Z, which is on the end of the second calendering roller K. This roller communicates motion, by means of a wheel on its opposite end, to all the remaining rollers except R, which is turned merely by the friction of the sliver passing under it. The above description applies principally to the elevation fig. 5; some of the parts are, however, best seen in fig. 6, which is a plan of part of the machine, viz., with the upper rollers omitted. The ends of the calendering rollers K, K are represented as being supplied with screws, which are for attaching the apparatus for conducting the steam for heating them. Referring now to the description of the several motions which are traced above to the pulley Z, and the end of the second roller, opposite to where this pulley is fixed, is provided with a cog wheel, which, by means of the connecting wheels or dead centres g, g, communicates motion to the first calendering roller D. These connecting wheels g, g are arranged to allow just so much increased velocity to the calendering rollers as will keep the sliver tightly stretched; from the lower second drawing roller motion is communicated to the first drawing rollers, and from thence to the carrying rollers. To give motion to the pressing roller, an additional wheel a is placed on the axis of the first lower drawing roller, which, by means of the connecting wheel on the dead centre e, communicates motion to the large wheel f, on the axis of the lower pressing roller P. The upper rollers generally revolve by their pressure on the lower ones, except the upper calendering rollers, which are provided with cogged wheels to work in the wheels I, I, seen in the lower calendering roller, and which are used for the purpose of making their motions steady and uniform. *Repository of Arts*, vol. xlviii.

Fig. 8.

All the subsequent operations of roving, spinning, twisting, and doubling, differ only in degree from those already illustrated in cotton, flax, silk, &c., it would therefore be useless to repeat the description; it is sufficient to refer to fig. 6, plate lxix.

Weaving.

Weaving.

(1031.) In the preceding description of different
VOL. VIII.

manufactures we have only traced the several operations as far as they relate to the object of reducing the raw material into the state of yarn or thread; it remains now to explain the subsequent processes by which these threads are converted into cloth or other fabric. The yarn or thread employed in weaving is of two kinds, commonly differing considerably from each other in regard to their hardness or twist, the hardest or most twisted being used for the warp or longitudinal threads, and the softer or less twisted for the weft or transverse threads.

Mechanical
Processes.

The form in which the material is sent from the spinning and doubling or twisting mills is that of hanks or skeins; those which are to be employed as warp are now wound on to bobbins, and from these the warps are formed by the operation of what is called *warping*, which is differently effected in different manufactories, but most commonly by a warping mill, the form of which differs also very considerably. The following is not an unusual construction.

Warping mill.—Four strong posts are connected by cross pieces forming an exterior frame, (see plate lxxiii. fig. 1.) within which is a stout wooden axle with an iron toe at the bottom; this works in a cup fixed on the lower transverse beams, and an iron axle or pin above passes through a hole in the upper transverse pieces so that the axle may revolve vertically; radii proceeding from this carry eight or more long wooden rods, which form thus a large vertical reel from six to seven feet high and about the same in diameter. One of the four posts we have described is broader than the rest, or double, and on this slides freely a block of wood called a jack. This is suspended by a cord, which, passing over a pulley at the top of the post, is carried and made fast to the iron spindle or axle, so that, as the reel revolves, the jack is raised gradually from the bottom to the top, and when the mill is turned the other way it descends by its own weight, and thus carries the threads of the warp gradually up or down in order to lay them smoothly on the reel.

Warping
mill de-
scribed.
Pl. lxxiii.
Fig. 1.

The frame carrying the bobbins differs considerably according to the nature of the material which is to be warped. The method shown in the figure is the old form of silk warping. The bobbin tiers are placed vertically, but generally, in warping cotton or worsted, they run horizontally in a large frame called the travers, which will carry 100 or more bobbins. In front of this frame, that is, on the side towards the reel, are placed two long rows of glass rings, and one thread is passed through each, the threads from the upper bobbins passing through the upper rings, and the lower threads through the others. These ends are now all united together in a knot; this is passed through the runners of the jack, and thence to the mill, where it is made fast, the jack being at the bottom; the mill is then turned round by the handle attached to the bench, seen in the figure, the jack rising and distributing the warp uniformly through a certain number of revolutions equal to the proposed length of the piece of cloth, a proper allowance being made for the shortening in weaving. When the jack has risen to its proper height, the warper collects the threads with his finger and thumb, placing one of the upper and one of the lower threads alternately, and also crossing them, forming what is called the lease. These are then passed in this form over pins on the mill, and returned the reverse way over the same pins, when the motion of the mill being also reversed the jack descends, doubling thus the number of threads; at the bottom the

Manufac-
tures.

warp is again passed over pins, but the threads are not gathered alternately; the motion is now again reversed, and when at top the former operation is repeated till the proper number of threads are collected to form the breadth of the cloth, which depends of course upon the number of bobbins employed and the number of threads in the piece. The crossing of the threads is now preserved by a band tied through them at top, and the crossing of the clues at the bottom by another band, and the warp is then removed by the warper, who, generally taking it off from the lower pins, winds it round his left hand in the form of a ball, crossing and recrossing the direction to prevent its unwinding or slipping. In the case of striped goods it is the business of the warper to arrange the different coloured bobbins in their proper order to give the stripes or shades required.

Beaming.

(1032.) *Beaming*.—In the state last described the warp is received by the weaver, which is now to be wound on a large beam the breadth of the intended piece of goods. This beam has iron pivots, on which it turns. In the beaming, the weaver sometimes employs a rude sort of instrument called a separator or ravel, which consists of a number of shreds of cane fastened together and fixed to a rail of wood like the teeth of a long comb, and the alternate crossing of the several clues in the warping serve to facilitate this arrangement and to spread the warp threads uniformly over the beam in the order in which they were laid by the warper. The warp beam is marked B in fig. 2, which is a simple form of loom next to be described.

The form of looms differs considerably from each other in different manufactories, as also in their dimensions, but the general principle of construction is nearly the same in all.

Drawing.
Pl. lxxiii.
Fig. 2, 3.

Before describing the loom, however, it will be well to refer to two of its appendages, the heddles and the sley or reed; the former is represented by *aa, bb*, fig. 2, and the latter at R, fig. 2, 3. Through both these it is necessary to pass every thread on the warp beam before the operation of weaving can commence. This process is called drawing, and is thus performed: the warp being regularly wound, as above described, upon the warp beam, the weaver must pass every yarn through its appropriate eye or loop in the heddles; this operation is called drawing. Two rods are first inserted into the lease formed by the pins in the warping mill, and the ends of these rods are tied together, the twine by which the lease was secured is then cut away, and the warp stretched to its proper breadth. The yarn beam is suspended by cords behind the heddles, somewhat higher, so that the warp hangs down perpendicularly. The weaver places himself in front of the heddles, and it is the business of another person, placed behind, to select every thread in its order, and deliver it to be drawn through the open eyes of the heddles. The succession in which the threads are to be delivered is easily ascertained by the lease rods, as every thread crosses that next to it. The warp, after passing through the heddles, is drawn through the reed by an instrument called a sley or reed hook, and two threads are taken through every interval in the reed.

The lease rods being passed through the intervals which form the lease, every thread will be found to pass over the first rod and under the second, the next thread passes under the first and over the second, and so on alternately. By this contrivance every thread is kept distinct from that on either side of it, and if broken, its

true situation in the warp may be easily and quickly found; this is of such importance that too much care cannot be taken to preserve the accuracy of the lease. There is likewise a third rod which divides the warp into what is usually called *splitfuls*, for two threads alternately pass over and under it, and these two threads also pass through the same interval between the splits of the reed. These operations being finished, the cords or mountings which move the heddles are applied, the reed is placed in the lay or batten, and the warp is knotted together into small portions which are tied to a shaft and connected by cords to the cloth beam, and the yarns are stretched ready to begin the weaving.

(1033.) *Loom*.—One of the simplest of these machines is represented in plate lxxiii. fig. 2, in which *AAA*, &c. is a frame of woodwork forming the exterior of the loom. *B* is the warp beam, or that on which the warp is first wound; *aa, bb*, are heddles; these consist of threads of a particular kind fixed to the rods *a, b*; they are looped about their middle part, as will be more particularly described below, and through these the threads of the warp, as they were gathered by the warper, are passed, *viz.*, alternately through *a* and *b*; these are suspended over two pulleys *P* above, and are attached below by lines to the treadles *D, E*, so that when one treadle, for example, *D*, is depressed, the heddle *b* will be depressed also, and the other heddle *a* and treadle *E* will be raised, and by this means every thread passing through the former heddle is depressed, while the alternate threads passing through the other heddle will be raised, leaving an opening between, called the shed, for the passage of the shuttle. *G H H R* is a frame, known by different names in different towns and manufactories; it is called the *batten*, the *lay*, the *lathe*, the *boards*, &c. It swings on the upper part of the frame at *XX*, and is furnished below with a sort of framing to receive the reed *R*, the nature of which has been described in Art. 456; through this reed the threads of the warp are passed after leaving the heddles, and are thence passed to the cloth beam at the commencement of the process. The purpose of this and of the swinging position of the lay is to drive up each line of weft passed through by the shuttle to its proper closeness, according to the nature of the material in hand.

Formerly, and even at present, in many worsted looms the lower bar of the lay was only sufficient to reach from side to side of the vertical bars *H, H*, so that the weaver, reaching forward, threw the shuttle through the shed with one hand and caught it in the other, and then back again, and so on; but it is now nearly a hundred years since the fly shuttle was first invented, and for nearly that time it has been generally employed in the cotton manufacture, and certainly ought every where to be adopted. The principle of this invention may be thus described: the bottom bar of the lay is broader than the rails *H, H*, and project before their plane about an inch and a half forming a shelf called the shuttle race; the ends of the shuttle race have thin boards screwed on to form two troughs or boxes *I, I*, seen best in fig. 3, in which pieces of horn or thick leather *K, K*, called peckers or drivers, traverse. Each pecker is guided by a wire above, fixed at one end to the rails *H, H*, and at the other to the end pieces of the troughs *I, I*; this part is shown more enlarged in fig. 4. Each pecker has also a string fastened to it, tied to the handle *h*, which the weaver holds in his right hand when at work, and with which he jerks the peckers backwards and forwards alternately to the

Mechanical
Processes.

Common
looms.
Figs. 2, 3, 4

Manufactures.

right and left, and thus drives the shuttle also backward and forward through the shed.

We have already mentioned the reed R; this is fixed upon the shuttle race k, and is shut down in its place by a cap piece not shown in the figure, but which is attached to the rails H, H; this upper rail the weaver holds in his left hand, and by this means drives up the lay against each line of weft as it is thrown across by the shuttle.

Shuttle.
Fig. 5.

The shuttle, enlarged, is shown in fig. 5. It is a small piece of wood pointed at each end, from 3 to 6 inches or even to 10 or 12 inches long, having an oblong mortise in it containing a small bobbin or pin on which the yarn to form the weft is wound; the end of this yarn runs through a small hole in the side of the shuttle, called the eye, and when it is thrown by the peckers as above, it is furnished with two small wheels or runners on the under side by which it runs easily on the shuttle race, but when it is thrown by hand, these wheels are not introduced. The lines S, S, fig. 2, represent two smooth rods put between the yarns to preserve the lease and to prevent the threads from entangling; commonly for such goods as are dressed in the loom, three such rods are used. The dressing in the loom is effected by two long brushes wetted with size, one applied below and the other above, between the warp beam and the heddles, but in weaving conducted by machinery it is now done before the warp is beamed.

The entire process of weaving in this simple form will be sufficiently comprehended. The weaver seats himself upon the seat M, and applies his feet to the two treadles, alternately pressing upon one and allowing the other to rise; this opens the threads as already described; he then jerks the shuttle through from one side to the other, then with his left hand he pulls the lay towards him, and thus drives up the yarn of weft left behind by the shuttle; he then presses down the other treadle allowing the first to rise, thus crossing each alternate thread; he then passes the shuttle again, and so on, winding his cloth every now and then upon the cloth beam which draws it off from the warp beam, the friction of which is properly adjusted by the weights w, w to preserve the threads at a proper degree of tension.

Different branches of weaving.

(1034.) *Different branches of weaving.*—In the preceding part we have given an idea of the very simplest form of the weaving Art, viz., the forming of plain cloth, in which each thread of the weft passes over and under a thread of the warp alternately, two leaves of heddles and two treadles only being necessary for the purpose; but weaving in general is a much more varied Art, and in its most simple elementary division may be considered as consisting of the following distinct branches, namely, plain texture and twilling, double cloth, spotting, flushing, and cross texture. All the diversity of which these fundamental branches are susceptible arises from the manner in which the threads of the warp are separated, or the sheds opened to receive the weft. As far as we have hitherto gone the threads are opened alternately and an equal quantity of the warp is laid on each side. In other cases, the warp is laid more prominently on one side, in others the weft, in others again these changes occur at certain intervals, and in certain order, producing stripes, spots, checkered work, flowers, figures, &c.; the simplest of these forms is still produced by a certain number of heddles and treadles, and the operation of raising the figure is produced by the foot of the weaver, but in the more complicated works

recourse must be had to a draw boy, or to machinery to supply his place.

Mechanical Processes.

In all these cases the essential parts for performing the operation are the heddles, hitherto but slightly mentioned, which it will now be necessary to describe more particularly.

The heddle is differently formed for different works: some are what are called clasped, as represented at A, fig. 8; others are made with eyes, as at B; and those employed in cross textures have half heddles attached to certain parts to assist in crossing the threads of warp. The clasped heddles are chiefly in use for plain fabrics, or where little mounting is necessary: in these the threads of warp enter between the clasps, where the dot is shown in the figure; and when the warp is weak or soft in the undressed state, the clasps when drawn together prevent it in a considerable degree from being unequally strained behind the mounting. The eyed heddles are principally used in fancy works, as in these the eye passes with more facility over any obstructions which may remain on the warp after dressing. In some cases, when eyed heddles are intended for the lighter fabrics of cloth, one single knot of the twine is sufficient to form the eye, as represented in the figure at a, but for the stouter fabrics, such as the general run of customary weaving, the eye requires two knots to prevent it from slipping, as at b.

Heddles. Parts of the loom described. Pl. lxxiii. Fig. 8.

Each leaf of heddles is fastened to two shafts, one above and one below, by means of cords called the maitland cords, or backings, on which they are knotted at proper distances for the given reed, or to produce a variety of patterns from the same mounting. In fancy mountings, however, when adapted to any particular pattern, it is more advantageous to have each portion of the heddles cast or knotted on the cords opposite those spaces of the cloth which they are respectively to weave.

Different methods are employed for lifting and depressing the heddles, such as simple treadles, or treadles connected with coupers, marshes, jacks, &c.; these are severally represented in figs. 6, 7. In fig. 6, 1, 2, 3, 4 are sections of the treadles, A are the coupers, B the long marshes, C the short marshes, and in fig. 7 u and v are jacks. In all looms mounted with coupers, except those for cross warps, each leaf of heddles has its couper and its long and short marshes. The coupers are placed in the frame D, fig. 6, called the top castle, or heddle bearer, which rests on the side of the rails i i, and are kept in a horizontal position during the process of mounting by means of another small frame; the ends of the coupers, which are immediately over the centre of the loom, are connected to the upper shaft of their respective leaves by the bow cords n, n, which, in general, are tied at the distance of about one-fourth of the breadth of the web from each side. The other ends of the coupers project over the web towards the side of the loom immediately above the ends of the long marshes to which they are respectively connected by the cords e. The long and short marshes are fixed on their centres by small bolts into the marsh frame m at the opposite side of the loom. The short marshes are tied to the under shaft of their respective leaves, and in a horizontal position equally distant from the leaves and long marshes, and at a sufficient distance from both to prevent their coming in contact with the sheds when open.

Mountings with treadles, coupers, marshes, &c. Pl. lxxiii. Fig. 6, 7.

In jack mounting, A, fig. 7, is the heddle bearer, which, as in the last mounting, is supported by the side

Mounting with jacks.

Manufac-
tures.

rails or capes of the loom, which are seen in section at *i i*. B shows the two leaves of heddles, *u, v* the two pair of jacks suspended from the heddle bearer by their centres, *n* are two small rods in the under doups or bows of the two leaves respectively. When these rods are drawn up to the clasps of the heddles by the handle *o*, the clasps are opened and the threads of the warp are permitted to pass through them without obstruction. At *x* are two spring shafts which form the connection between the under shafts and their respective short marshes *y*. G is a part of the marsh frame, and *t, t* are the ends of the treadles. By examining the figure, it will appear that each jack is connected by one end to one leaf, and by the other to the other leaf, so that it would seem that one jack at each side of the loom would be sufficient for a plain fabric; but it is usual to apply two jacks at each side of these mountings for steadiness, one crossing the other, which, when the loom is at work, move always in opposite directions.

Other
forms of
mounting.

There are other methods of mounting jacks, principally with a view to facilitate the shifting back of the heddles, one of which is common, that is by what are termed tumblers, for slacking the heddles above when requisite; but the method we have described is the most simple, and at the same time equally convenient with any of the others. In order to avoid the crossing over the treadles by the weaver, in producing the required figure, different methods of arrangement have been adopted. In spot mountings, and such others as have part of their ground woven plain, the plain treadles are usually placed in the centre, and those which are destined for the figured parts at each side, as nearly as possible in equal portions. In tweels and all the varieties in which the treading is straight over the treadles, if these are numbered in order, it is plain that the right foot, when it commences the tread, will work on all the odd numbers, and the left on the even ones. Suppose, therefore, all the odd numbers to be placed together at the right side, and the even ones at the left, then the treadles may be so corded that the treading may either commence in the centre and proceed outwards, or on the outsides and work towards the centre, or, which is frequently the case, that one foot may commence at the outside and the other at the centre, and both work towards one side: thus, for example, if we take the treadles of an eight-leaf tweel whose progressive order would be 1, 2, 3, 4, 5, 6, 7, 8, then, in order to work them with both feet without crossing, they may be arranged in any of the following orders, viz.,

Order of
treading.

8, 6, 4, 2, 1, 3, 5, 7,
2, 4, 6, 8, 7, 5, 3, 1,
8, 6, 4, 2, 7, 5, 3, 1.

In some other kind of weaving, such as crapes, where one treadle works against a number, the left foot usually rests on the treadle, and the right foot works over the others in all the varieties. In other cases, when only part of the treadles can be worked alternately, as in velveteens, &c., two or more successive treadles are placed together, either for the right or left foot at pleasure, and the weaver treads these in succession with one foot and then works the other alternately. In some cases, however, additional treadles are employed to make the treading equal; and in some cases, as tweels, with an odd number of leaves, all the treadles are placed in their natural order, and the weaver works over them all with one foot; or when the treading returns in the same

natural order, as in lined work, he works over the treadles from one side with one foot, and from the other side with the other foot. It frequently occurs also, that one or more leaves are to be raised occasionally with some of the leaves which form the principal sheds. In such cases the treadles of these occasional sheds may be omitted by screwing a small piece of wood, such as a piece cut off from an old shaft, to the point of the principal treadle, and applying it to the treadle cord of these additional leaves. These attached pieces are called tongues, and while the weaver continues to work the ground, he keeps his foot on the principal treadle only, but when the additional leaves are to be raised, he slips his foot forward on the tongue and presses it down with the treadle.

Mechanical
Processes.

From what has been said, it will be seen that the more complicated the figure the greater must be the number of the leaves of the heddles, and the greater the number of treadles, while this method of opening the sheds is only had recourse to, and accordingly great ingenuity has been exercised in producing the desired effect; thus in some instances, in order to comprise as many leaves as possible in a small compass, the heddles are made of different depths, and their respective shafts raised one tier above another, to a sufficient height to prevent them from touching when the sheds are opened. For example, if a mounting were to consist of ninety leaves, which is not uncommon for some of the finer kinds of silk woven in England, and the shafts made about one-eighth of an inch thick, the whole, by arranging them in three tiers of thirty shafts each, might be comprised within the space of five inches.

(1035.) Before the invention of machines for opening the sheds of large mountings, the place of the greater number of the treadles was usually supplied by a draw boy. If the loom were mounted with couplets, the ends of all the couplets of those leaves which were to be raised from each shed were connected to a cord which descended at the side of the loom, and, passing through a hole in a horizontal board which regulated the distance of the cords, had a weight appended to it to keep it straight and to sink it after being raised. Each shed of the pattern had therefore its respective side cord, and the whole were arranged in a straight line in the hole board, in the same order as the sheds of the pattern occurred, so that the draw boy had only to pull them in succession along the board as the sheds were required by the weaver; and if to save room pulleys are employed instead of couplets, then it is evident that the cords must be selected and tied to the side cords, but in this case a small tail would be necessary.

Draw boy.

This simple mode of arranging the cords which thus open the number of sheds of the most extensive patterns woven with leaves, is inserted merely to convey to the reader a distinct idea of the general principle on which a great variety of machines have been constructed to supersede the use of the draw boy in the different branches of weaving; for however much these machines may vary in their form, or to whatever species of weaving they may be applied, still it must be kept in view that all the leaves that would have been raised by any particular treadle must here be selected and raised by the moving part of the machinery. We shall, however, only illustrate the preceding observation by a description of one of these machines of the most approved construction. Fig. 7. pl. lxxiv. is a front view of a machine called the *parrot*, from the pecking motion

Simple
substitute
for the
draw boy.

Pl. lxxiv.
Fig. 7, 8,
9, 10.

Manufac-
tures.

of that part which pulls the side or knot cords; the ends of the couplets are seen at *A*, and are numbered from 1 to 10 inclusive; the knots, or more frequently beads, which are caught by the parrot *e*, appear on the cords at *a, a*, which cords are arranged in a straight line, and kept at equal distances by the two hole boards *B, B*. At *C, C* are leads or weights appended to the knot cords, which are, in the present instance, fourteen in number. The parrot *e* is movable along the square axle *o*, and is turned round by pressing down the treadle *i*, which is attached to the wheel *D* by a cord round its rim; the cord *w* is fastened to the parrot, and after passing through a hole in the wheel *D*, it is wound about the inner part of the wheel *X*, which is turned by the hammer *E* working in its teeth. Whenever, therefore, the weaver has occasion to shift the parrot from one knot cord to another, the hammer *E* is raised by a treadle, and, falling by a weight attached to it, the cross wire *y* catches one of the teeth and moves it one tooth round; thus the length of each tooth must be such that the fork of the parrot removes exactly the distance of one bead from another. Fig. 8 is a side view of the parrot as it is mounted for a double row of knot cords, which are necessary when the sheds of the pattern are numerous; fig. 9 is a view of the wheel *D*, with the hole *z* through which the cord *w* runs; fig. 10 is a front view of the wheel *x*; *p* is another wheel on the same axle, but movable on that axis; *m, n* are two studs which regulate the number of sheds in the pattern; for when the wheel *x*, which is fixed on the axle *o*, brings the handle or index *q*, by means of the stud *n*, round to the catch *s*, which takes place always at the end of the pattern, the catch *s* is raised out of the teeth, and the weight *t*, fig. 7, draws back the parrot till the stud *n* comes round to the handle *q*, which it displaces, and allows the catch *s* to fall again into the teeth of the wheel where the pattern is to recommence. From an attentive view of fig. 7 it is easy to perceive how the couplets and knot cords are connected for each shed; for example, were the third, fifth, and sixth leaves to be raised for the first shed, each of these couplets would be connected to the knot cord No. 1, at *g*, and so for every shed of the pattern.

French
draw loom.
Pl. lxxvi.
1, 2, 3.

(1036.) It would be impossible to give a description of all the different kinds of draw looms which have been invented within the last thirty years, we shall therefore confine ourselves to one only, commonly known as the French draw loom; this has neither tails nor lashings, and the pattern, which is cut out in small pieces of pasteboard, may be changed without the weaver's stopping his shuttle. The harness of this draw loom is represented in plate lxxvi. fig. 1; it is constructed from the neck upwards similarly to the common draw loom, having knot cords arranged in nearly the same manner, but only one trap board. *E* and *A* are the carriage and uprights; *C* the knot cords, and *a* the trap board; *z* are needles or pieces of wire, one attached to each knot cord by taking a turn round it; *d* is what the weavers term a cylinder or barrel, though it is a square beam of wood, perforated with holes on each of its four sides, equal to the number of the needles employed, as exhibited in fig. 4. The barrel, besides its rotary motion, vibrates on pivots like a pendulum; *b* are small pieces of pasteboard, about ten inches long, and from two to three broad, perforated with holes to receive the ends of the needles, and are arranged agreeably to the order of the tacks in lashing the pattern for

Mechanical
Processes.

the other draw looms, as shown in fig. 3. There is one of these pasteboards for each lash; and all the boards for one pattern are connected together like an endless chain, with twine, at equal distances, so as to fit exactly the flat faces of the barrel; *g* is the receptacle for the pasteboards, which, in some looms, is composed of thongs of leather suspended from the guide *s* at one end, and from the cape of the loom at the other; in other looms it consists of parallel slips of wood connected together with cords. *D* is a lever for raising the trap board, to which it is connected by means of the circular pieces of iron *x*, one on each side, with a bar across, to the centre of which the end of the lever is connected by a piece of wire; *o, o* are cross bars of wood, with holes in their centres, through which runs pieces of strong iron wire fixed into the trap board at each side to keep it steady while in operation. At *m* are spiral springs for regulating the motion of the needles, and into the cross bar of wood *r* is inserted another piece of wood, moving on springs which yield to the pressure of the needles; these are forced back by the barrel, and recover themselves when the barrel is withdrawn; fig. 4 is an end view of the barrel with the apparatus for turning it round, which, like the rest of the machine, is extremely simple. It consists of two catches, *b, c*, which are attached to the opposite end of the frame; when the barrel is turned round from right to left, the catch *b* is lowered by means of a cord connected to a treadle, till the tooth of the catch *i* comes in contact with the corner of the barrel in its motion backwards and turns it round, till a new face and pasteboard are presented to the needles, and when it is turned from left to right, the catch *c* is employed in the same manner; *z*, fig. 1, is a cord connected to the barrel, which, after passing over two pulleys, has the direction seen in the figure, and is tied to the end of a long march; *y* is another cord which descends from the lever *D* to another long march; and these two marches are connected to separate the treadles, which are wrought alternately.

From this description of the machine its mode of operation will be obvious. The weaver presses down the treadle which pulls back the barrel *a* by means of the cord *z*, and in this state all the knot cords are drawn into the saw draughts of the trap board. As this treadle is relieved and the other pressed down, the barrel is drawn by springs against the ends of the needles, which enter into the pasteboard wherever there is a perforation; but where there is none, they are driven back, and, consequently, drive their respective knot cord out of the saw draughts of the trap board, which are then allowed to remain stationary while the others are raised.

The reading of the patterns on these pasteboards is the only tedious process connected with the machine. The method in common use is for one person to read over the tacks of the design, and another with a punch to strike out the holes in the pasteboard, agreeably to his instructions; thus on the line 1, fig. 3, there are three dots which denote three holes for the wires. The person who gives the instruction says, take three, the other person then strikes out these three holes with the punch; then, as there is a blank on the upper cross line and two on the under line at 2, three are ordered to be passed; then two on the line 2, and three on the line 3, are next to be cut out, and so on, always beginning at the bottom of the lines, as in the process of taking

Manufac-
tures.

the harness twines through a hole board. In this example there are only four cross lines or rows of holes, but in practice there are eight, corresponding to eight horizontal rows of the needles; the four small holes at each end of the pasteboards are for lacing them together agreeably to the succession of the lashes. The large holes *a, a* are made to fit the studs *a*, fig. 4, on the ends of the barrel, by which the pasteboards are drawn into their proper positions to receive the ends of the needles.—Murphy, *on the Art of Weaving*.

It is impossible within the limits of this article to give any extended view of the great variety of looms and loom mountings which the ingenuity of our manufacturers have introduced for the various kinds of weaving performed on the several different materials thus employed. In the above we have confined our remarks to the simplest operations, and must refer the reader, who is desirous of a minute and extensive description of the Art, to the Treatise by Mr. Murphy, above referred to, to which we have been largely indebted both for figures and description; and from the same ingenious author we select the following description of machinery for weaving by power.

Power loom
described.

(1037.) *Power loom*.—We have already, in our historical introduction to the Cotton Manufacture, stated some particulars relative to the invention of the power loom, and the different forms it has assumed in different manufactories, and have slightly alluded to the dressing machine, the invention of which was so necessary to the success of the attempts for weaving by power. It remains for us, therefore, only to give to the reader, in this place, a concise description of a simple machine of this kind, for which, as above stated, we are indebted to Mr. Murphy. This is represented in pl. lxxv. fig. 1, 2; the former being a front elevation, and the latter a profile. In fig. 1, *A* is the cloth; *B* the boxes of the lay; *o, o* the drivers; *c* the swords of the lay; *D* the heddles; *n* the reed; *a* fast and loose pulleys; and *i* the spring for putting on and taking off the power; 1, 2, 3, 4 are the ends of four treadles, two for opening the sheds, and two for driving the shuttle; *w* is the driving pin attached to the pulley *z*, over which there is a belt with cords attached to the two outer treadles 1 and 4; *x, x* are the wipers, and *y* the driving cord. In fig. 2, *a* is the yarn or warp roll; *b* the rods for preserving the lease; *A* the box of the lay; *c* two pairs of temples for keeping the cloth stretched; *B* a spur wheel on the axle of the cloth roll, which assists in rolling up the cloth. The fast and loose pulleys represented at *a*, fig. 1, are seen in this figure at *d*, and on the axle of these is the spur wheel *i*. The reciprocating motion of the lay *A* is given by means of the rod *e*, which connects it with the rim of this wheel, and there is a similar rod on the other side of the loom attached to a crank. The wheel *C* is driven by the wheel *i*, which, by its revolutions, drives the wipers *v, v*, fixed on its axle. These wipers act by their circumference on the treadles 2, 3; and as they are circular at their greatest distance from the centres, the motion of the heddles is thereby suspended while the shuttle is passing through the warp: on the outside of each wiper is a circular knob movable on its axis, and on the shuttle treadles 1, 4 are fixed the friction rollers *n*. When, therefore, these knobs strike the friction rollers, they give motion to the shuttle by means of the driving stick *w* and cord *y*, fig. 1. It must be observed, however, that the knobs are so fixed to their respective wipers, that the sheds

Pl. lxxv.
Fig. 1, 2.

may be fully opened before the shuttle receives its impulse; this is done by shifting them backwards or forwards in grooves cut in the wipers for the purpose. *B* and *j* are the wheels for winding up the cloth, the former being driven by a spindle on the axle of the ratchet wheel *j*, and this last is turned round by a catch attached to the top of the lever *x*; this lever has a reciprocating motion given to it by a stud in the sword of lay *s*, fig. 1; as this catch is moved by every stroke of the lay, it cannot command a tooth of the ratchet wheel at each shot, but reciprocates over one tooth till as much cloth is woven as will allow it to take hold of another tooth, the other two catches represented in the figure taking hold of other teeth alternately. The apparatus which stops the loom when the shuttle meets with any obstruction is next to be considered. Along the back of the lay *A*, fig. 2, runs an iron rod connected with a spring *g* at each end; this rod is also connected with two circular pieces of wood, one in each box in the lay, so that when the shuttle goes into the box, this piece of wood is driven back and acts upon the rod so as to raise a small plate of iron which covers a circular hole in the centre of the lay. When, therefore, the lay and shuttle are in operation, the iron plate is raised at each shot, and permits the stud *h* to pass through without obstruction; but when the shuttle flies out of the shed, the iron plate covers the hole and strikes with force against the stud *h*, which is connected with a disengaging rod, and throws the belt off the fast on to the loose pulley, which stops the loom. In fig. 3, 4, we have given a front elevation of another power loom as constructed by Messrs. Sharp and Roberts, of Manchester: its operation is sufficiently obvious from the drawing.

Mechanical
Processes.

Pl. lxxv.
Fig. 3, 4.

(1038.) *Double cloth weaving*.—We have said that it is impossible for us to attempt describing the various kinds of fabrics produced by the loom in a concise article of this kind. As far as we have gone the reader can form a general idea of the means had recourse to for producing plain and twilled and lined cloth and fancy work, in which the figure is found by raising different sheds, and thus leaving the weft and warp differently prominent to give the various figures; but, besides all these varieties, there are made what is called double cloth, velvets, velveteens, corduroys, cross textures, such as gauzes, linens, &c., some of which are so peculiar that a short description will be interesting to the curious reader.

Double
cloth.

Double cloth is generally composed of two similar fabrics interwoven at various intervals and formed into a diversity of figures agreeably to design of the pattern to be produced: this is the method commonly followed in carpet weaving. In some cases one of the materials is superior to the other, as in bed quiltings, in which the superior forms the face and the inferior the back, therefore, in explaining the principles of this branch of weaving, it will be necessary to refer to these methods separately. In order to comprehend more easily the first process, we may take for an example the warp of any plain fabric, of which we may suppose one thread to be blue and one white alternately, and that this is drawn through a common four-leaved set of plain heddles in the usual way; then it will appear, from the arrangement described below, that when the draught commences with a blue thread all the other blue threads will be drawn on the two back leaves at 1, 3, 5, 7, &c., and all the white threads, as numbered 2, 4, 6, &c., will be drawn on the two front ones. This is exhibited in fig. 2. pl. lxxvi., in which *A, B, C, D* represent the

Manufac-
tures.

Pl. lxxvi.
Fig. 2, 3.

treadles each connected with its respective heddles, which are denoted by the horizontal lines, and marked blue or white, according to the thread they are supposed to carry. Now,

1. When the two back leaves are raised and sunk alternately with the two fore ones and white weft thrown across, the whole fabric, which is plain cloth, will be formed in two stripes nearly entirely blue and white, and if a shot of blue and a shot of white be thrown alternately, a corresponding check will be produced. These sheds will be opened by the treadles A.

2. If the two fore leaves were constantly sunk and the back leaves raised alternately, it is plain that, by throwing in blue weft, all the blue warp would be woven into a uniform blue fabric, leaving all the white warp unwoven below. This would be effected by the two treadles marked B.

3. If the two back leaves were constantly raised and the two fore leaves raised alternately, a white fabric would be produced by throwing across white weft, leaving out the blue warp above, as marked at C.

4. And in like manner all the blue warp is sunk and white cloth woven by the treadles D.

5. The white warp is all raised and blue cloth produced by the treadles E.

By consulting the above description, and by referring to the figure, it will be manifest that each of these webs may be woven separately and distinctly from the other, either when the blue or white warp is uppermost. But the manner in which they are woven together and made to pass through each other at pleasure will be seen by what follows.

If the plan shown in fig. 3, 4, be attentively examined, it will be found that in the former, fig. 3, where the white warp is above, when the treadle marked 10 is pressed down, one blue leaf is raised and the other sunk, while all the white warp is raised above the shuttle, therefore one shot of blue weft is thrown into this shed to form the blue fabric. Now when the treadle 8 is pressed down it raises one white leaf and sinks the other, while at the same time all the blue warp is sunk quite clear of the shuttle; into this shed the first white shot is thrown; the treadle marked 9 reverses the blue shed keeping the white warp still above. Into this shed the second blue shot is thrown, and the treadle 7 sinks all the blue warp and reverses the white shed for the second white shot. The numbers on these treadles refer to those in fig. 3.

By following this process, the two webs would be woven quite distinct from each other, the white above the blue below; but when the treadles marked 4 are employed, the two webs will change places, that is, the blue web will now be above and the white below. Hence, if only one shuttle were employed for both webs, so long as the weaver continued to work upon one set of treadles, the two webs would still be distinct, except at the selvages, where they would be united by the weft.

Without entering into a more minute description, it will be obvious that, by different arrangements of the heddles and treadles, the two warps may be interwoven at any intervals at pleasure, and consequently figures of all varieties produced on either one or both surfaces. For example, referring to fig. 2, 5, the weaver may work once over the treadles marked D, by which all the white warp on the divisions A and B will be woven above, and all the white warp in the divisions C, D will be woven below, raising the blue cloth to form the figure;

and this is effected by throwing in a blue shot on treadle 1, a white one on treadle 2, a blue one on treadle 3, and a white one on treadle 4. He may then work once over the treadles C, once over B, once over A, once over B, once over C, once over D, all in the same manner as at first, after which he may continue to work twice over the treadles A and B, three times over C, four times over D, and so on agreeably to the succession of the draught, and by different arrangement patterns may be woven in great variety. See fig. 6.

(1039.) *Finishing velvets, corduroys, &c.*—These goods, after they come from the loom, have their flushed

Mechanical
Processes.

parts cut up, the former into a uniformly smooth surface, and the latter into ridges. The piece is spread for this purpose on a long table, and the person who conducts the process runs the point of a sharp instrument, called a plough, along a furrow or centre of each flushed stripe; the piece is then exposed to the action of two strong brushes which are driven across the ridges by machinery with a reciprocating motion. At each end of the table is a roller, on one of which the cloth is wound before the operation, and the other with a very slow motion receives it as it comes from the brushes. The use of this process is to raise the pile and form the cut flushing into ridges above those parts which are incorporated with the warp. When the piece has passed through this machine, the loose fibres are singed off by drawing its surface over a cast-iron cylinder made red hot. It is then immersed in hot water and well rubbed with a hand brush, after which it is dried, singed, and again put through the brushing machine, these operations being repeated three times in succession.

The piece is next put into a tub full of hot water with which are mixed a little vitriol and pearl ashes: this ley is called a *chemic*. When it is taken out of the chemic it is spread on grass, where it lies two or three days, when it is again put through the chemic and rubbed well with a hand brush to remove any fire stains or brown spots that may be remaining. Two or three days more exposure to the air on the green will prepare it for dyeing the darker colours, but for the lighter shades it will require a little bleaching.

(1040.) *Plush velvet.*—This is woven on a somewhat

Plush
velvet.

different principle to the other fabrics described above. It consists of two warps, one called the main warp or ground, which is commonly made of hard silk, and the other the pile warp. These are beamed on separate rolls, the latter being placed below the former. When the heading or end of the piece is woven, the weaver raises the pile warp, which is drawn on a separate leaf from the ground, and into this shed he introduces a wire which is longer than the breadth of the cloth. A few shots of the ground are then thrown and another wire introduced, and so on with a third. In each of these wires is a groove, along which the weaver runs the point of a sharp instrument called a *trivet*, which cuts the pile and relieves the wires in succession. The first wire, therefore, when thus relieved, is again put into the fourth pile shed, and after a few shots of the ground are woven the second wire is inserted into another pile shed, and thus the operation is continued till the piece is finished. The pile warp is commonly made of softer silk than the warp, or of a fine kind of goat's hair, and the surface of the shag is afterwards cut evenly and smooth with a pair of shears. See Murphy on the *Art of Weaving*; Duncan on *Weaving*; and various volumes of the *Society of Arts* and the *Repertory of Arts*.

Manufac-
tures.Bobbin-net
manufac-
ture.*Lace and Bobbin-net Manufacture.*

(1041.) Besides the several fabrics of cotton silk, &c. described under the article *WEAVING*, there are several others in which weaving, properly so called, is not employed; such as bobbin net, hosiery, &c., to which we shall refer, but these branches are so numerous that we can only select one or two. The most important are those above named, and the former in particular is so illustrative of the advantages of machinery, and of the success of well-directed ingenuity even in the most difficult processes, that we cannot pass over this almost infant Art without endeavouring to give to the reader some idea of the process, and of its importance in a national point of view.

Bobbin net is a species of plain lace of a transparent texture, a fabric which, till within a very few years, was made at so slow a rate that it could only be used by the very highest classes of Society; and in order to show more prominently the extent of ingenuity which must have been exercised in the invention of machinery for this purpose, it will not be out of place to give a slight description, in the first instance, of the original method of forming the different kinds of lace on cushions.

Making
pillow lace.

(1042.) This was commonly made of thread or silk woven into a net, the meshes of which were varied in their figure according to the design of the pattern, as into hexagons, octagons, &c. This was also ornamented by a thread much thicker than the rest, so interwoven within the meshes as to form flowers, curves, and other figures, upon the beauty and elegance of which, and the uniformity of the meshes themselves, the value of the lace depended. This thick thread is called *gimp*.

The pillow or bobbin lace is made on a pillow or cushion by women and children, principally in this Country in Buckinghamshire and Bedfordshire. The operator places the cushion on her knees; the threads are wound upon bobbins, which are small round pieces of wood about the size of a pencil, round the upper edge of which a deep groove is formed so as to reduce the bobbin to a thin neck; and on this part the thread is wound, a separate bobbin being used for each thread. To give form to the meshes, pins are stuck into the cushion, and the threads are woven and twisted together around the pins; a piece of parchment is first fixed down upon the cushion, which has been previously pierced with small pin holes, to show the proper places for the pins, and on this parchment the design for the gimp or thick thread is also traced, to guide the woman in placing the gimp, so that it will be woven in between the fine threads which form the network. The work is begun at the upper part of the cushion by tying the threads together in pairs, and each pair is attached to a pin which is stuck through the parchment into the cushion. The round form of the cushion allows the bobbins to hang down by their threads on different sides, and on whatever side the bobbins are placed they will continue. At the commencement of the work all the bobbins are put on one side of the cushion, and are brought to the front side, four bobbins, or two pairs at a time, to be twisted together. The woman takes one pair in each hand, and with the finger and thumb twists the bobbins over each other three times; the effect of this is to twist the threads of each pair together, or round each other, and this is done by both hands at the same time. When the twisting, which forms the sides of the mesh, is thus completed, the adjacent bobbins of each pair are interchanged, in order to cross the threads

of those bobbins over each other, and make the bottom of the mesh. To render this clear, suppose the four bobbins numbered: No. 1 is twisted round 2, and 3 is twisted round 4; then, in order to cross, 2 and 3 are interchanged, so that 1 and 3 come together, and 2 and 4; and the next time that the twisting operation is performed these pairs of threads will be combined together.

When a mesh or half a mesh is made, it must be secured by putting a pin into the cushion; and in order to draw the twist work close, the pin is introduced between the recently crossed threads, and carried up towards the top of the pillow, so as to drive the twists and cross before it, and concentrate or draw the twists into a small compass; the pin is then inserted into its proper hole in the parchment, which prevents the threads from returning. These four bobbins are now done with for the present, and are put on one side of the cushion; then the two next pairs are brought forward into the front of the cushion, and are twisted and crossed in the same way; in this manner the work proceeds, till a row of meshes is formed all across the breadth of the intended piece of lace, and then the same bobbins are worked over again to make another row. In general, the number of bobbins and of threads is equal to 48 or 60 to every inch of breadth.

The work people perform these operations with great dexterity; but the work, nevertheless, proceeds very slowly, as it requires so many meshes to make a small piece of lace, and only one mesh is made at a time. Taking the threads at 50 per inch, if the piece of lace is one inch wide, it will have 25 meshes in the breadth, or 625 meshes in each square inch of length, or 22,000 meshes in a yard; and the price of a piece of lace of this description is seldom more than eighteen pence.

(1043.) This is sufficiently illustrative of the old form of lace-making; it will also give the reader an idea of the immense difficulty to be overcome before this process could be successfully imitated by machinery. The first attempt, it appears, was made about 1764 or 1770, when a machine was brought from Switzerland; and various attempts were made to improve it so as to produce a sort of plat, but the operation was found to be so slow and imperfect that it was soon abandoned. The next step towards the accomplishment of the object was the warp frame, which is a variety of the stocking frame, although the parts are differently arranged, all the movements being adapted to be produced by treadles, leaving the hands of the workman free to manage the machine, which is a piece of mechanism applied in front of the frame. Here the piece of lace is not formed of one continued thread as in the machine last referred to, but there are as many threads as there are needles in the frame; these are warped or wound upon a roller or beam, the same as the loom, and it is from this circumstance that the machine is called the warp frame, the former being denominated the point-net frame. The lace thus formed was more permanent than that of the point-net frame, and the process was quicker, but after all, this kind of lace never commanded great attention as an object of fashion.

(1044.) At length, in 1808, a Patent was taken out by Mr. Heathcoat, for the manufacture of what is now called bobbin net, which, it is said, originated by a workman, employed in making machinery for producing fishing-nets, seizing upon a hint which accident threw in his way, which led to the idea of making lace by warp and weft. The groundwork of the invention is to extend those threads which form the warp of the lace in parallel lines and to dispose the diagonal threads upon small bobbins

Mechanical
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Manufac-
tures.

which are detached and capable of passing round the extended warp threads so as to twist with them. By this means the number of bobbins is reduced one-half. There are two horizontal beams or rollers, one to contain the thread, and another to receive the lace, and a number of small bobbins to contain the weft thread.

These bobbins resemble the quills or pirns used in a weaver's shuttle, but are made very small, each bobbin being only a wire pin, round which the thread is lapped in the form of a small cone, and a slender spring is provided to cause just so much friction as will make the threads draw tight when pulled off from the bobbin. One of the rollers above mentioned is placed in the under part of the machine, and the other in the upper part, both in the same perpendicular plane; the threads intended to form the warp or longitudinal threads in the piece of lace are wound upon the lower roller and ascend to the upper, to which they are separately attached.

The bobbins are so arranged between these two rollers that the threads proceeding from them accompany the longitudinal threads to the upper roller and are attached thereto. Each of the longitudinal threads, in its way to the upper roller, passes through a conical tube, at the lower end of which is a small spindle, which is so supported as to admit of being turned round. On the upper end of the spindle is a taper tube, composed of two parts, which open longitudinally; one of the parts so divided remains attached to the spindle, and is thus sustained, partaking of the revolving motion of the latter; and the longitudinal thread which passes through the spindle is conducted through the hollow part of this half tube, and through a small eye at the extreme point of it. The other section of the tube, which, as has been said, can be separated from the spindle, contains within its hollow part the small bobbin on which the diagonal thread is wound; so that when the parts are placed together, each tube contains two threads, one the warp thread proceeding from the lower roller, and the other from the pirn or bobbin containing the weft thread enclosed in the movable half of the tube.

These spindles are mounted in collars, so as to be capable of turning round by means of the pinion at the lower extremity, and when so turned will twist the bobbin and longitudinal threads together. The number of these tubes or spindles is just equal to the number of pairs of each kind of threads, and their arrangement is such that all the pinions lie in the circumference of a circle, and the spindles and tubes converge towards the centre of the same circle as so many radii. The pinions can be all moved round at the same time by rackwork, the teeth of which correspond with the pinions. This motion is to cause the pair of threads contained in each tube to twist together, and this twisting, as is obvious from the description, taking place at the same time in all.

The crossing the diagonal threads, which is the next step, is performed at once in the whole breadth, as follows. That movable part of each divided tube which contains the bobbin of diagonal thread, or weft, is removed from the other portion by a very ingenious piece of mechanism, and brought forward altogether till they are entirely clear of the spindles; and during this time one half of them are caused to move one space to the right, and the other half one space to the left. The sifted parts are then put back again and attached to the spindle, but not to the same spindle, so that by this motion each spindle will have changed its diagonal thread,

VOL. VIII.

but the parallel or warp thread will remain. This effects the crossing of the threads throughout the whole breadth of the machine at the same time. Mechanical Processes.

The pins by which the uniformity of the meshes is preserved are all placed upon a movable bar, and are all inserted at once into the meshes formed by the two operations of twisting and crossing. The working of the machine is a constant repetition of twisting, crossing, and taking up the meshes.

This was the first successful attempt at bobbin-net weaving, (as it may without much impropriety be called;) it was much improved again by the inventor in the following year, when, instead of the limited breadth of lace which only could be formed by the machine last described, pieces might now be made of any breadth required. A Patent was secured, and it turned out a very successful speculation to those concerned, as well as a great advantage to the inhabitants, who thus found useful employment both for themselves and children. Important improvements in this process have, however, been made since the expiration of the Patent, which has enabled the present manufacturers to sell for half-a-crown that for which the original Patentees obtained five guineas. Subsequent improvements.

(1045.) This manufacture, so recent in this Country, has already extended to immense importance from the amount of capital it involves, and the number of hands which it employs, as will be seen by the following statistical view of it by W. Felkin, Esq., showing its state in 1831. Statistical view of the net trade.

Capital employed.

35 factories for spinning and doubling, principally in Manchester, value	£ 460,000
682,000 spindles and other machinery	375,000
Spinners' and doublers' stocks	100,000

Manchester total capital about £935,000

Capital employed in Bobbin-net Making.

22 factories, principally for power machines, value	80,000
Increased in two years, one-eighth in number, and one-sixth in capacity for production, 1000 power machines, average 10-quarter wide	150,000
Increased in two years, one-eighth in number, and one-sixth in capacity for production, 3500 hand machines, average 8-quarter wide	390,000
Stock on hand, power owners...	250,000
Ditto, hand ditto	150,000
	£1,020,000
Capital in embroidering, preparing stock ...	355,000

Total capital employed about £2,310,000

Its extensive influence is seen by the number of hands employed.

In Manchester, spinners (adults)	3000
Children	6000
Manchester and Nottingham doubling ..	4000
	13,000
In power-net making (adults)	1500
Ditto youths of fifteen or more ...	1000
Ditto children	500
Carried forward ..	3000
	13,000

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Manufactures.

Brought forward	3000	13,000
In power-net making, women in mending	2000	
In hand-machine working, nearly all men, only a few apprentices of fifteen or more, almost all at home, in shops.	5000	
Ditto children winding at home	4000	
Ditto children mending at home	4000	
		18,000

In embroidering, in almost every village within a circle of fifty miles round Nottingham, in Glasgow, Ireland, London, Devon, Somerset, and Norfolk, (women and children)	150,000
In mending, pearling, finishing.	30,000

Total number of persons receiving wages 211,000

The population of Nottingham, Lenton, Beeston, Radford, Barford, Arnold, and Snenton, in 1811, (the epoch of the commencement of the bobbin-net manufacture,) was 47,300, the present number of inhabitants is 79,000. The hosiery trade employs fewer hands in these towns now than it did then, and the point-net trade has much declined. No other branch of business has materially advanced or sprung up in the mean time, therefore this large increase of population may be fairly attributed to the bobbin-net manufacture. Besides this surplus 32,000 persons, a large proportion of the remaining population of this town and neighbourhood is dependent upon and chiefly employed in its various operations.

As a peculiar excellence of this trade, it may be remarked that, while 150,000 embroiderers are mainly dependent upon this employ, and work regularly, there are many others who are employed only at intervals of rest from household or other labour, the wages therefore go in aid of other trades half over England, and any diminution in this causes proportionate distress in other cases.

The advantages are again seen in a very prominent point of view, by the comparison of the value of the raw material when imported with the value of manufactured goods therefrom; thus the amount of Sea-island cotton annually used is 1,600,000 pounds, value £120,000. This is manufactured into yarn, weighing 1,000,000 pounds, value £500,000.

There is also used 25,000 pounds of raw silk, which costs about £30,000, and is doubled into 20,000 pounds thrown, worth £40,000.

The Cotton is worked into

6,750,000 square yards of net, worth 1s. 3d. per square yard, being on an average coarse 11-point, and nearly all in plain net...	421,875
15,750,000 square yards of hand net worth 1s. 9d. per square yard, being on an average fine 11-point, and two-thirds in quillings ..	1,378,125
150,000 square yards of fancy net, worth 3s. 6d. per square yard.	26,250

The Silk is worked into

750,000 square yards of silk net, worth 1s. 9d. per square yard	65,625
23,400,000 square yards, annual produce of bobbin net, of the present value of	£1,891,875

The brown nets, which are sold in Nottingham market, are in part disposed of by the agents of twelve or fifteen

of the larger makers, *i. e.* to the amount of about £250,000 per annum. The principal part of the remainder, *i. e.* about £1,050,000 a-year, is sold by about two hundred agents, who take the goods from one warehouse to another for sale.

Of this production, about half is exported in the unembroidered state, and in the white principally; yet a large quantity is sent in the unbleached state, and is embroidered abroad, and much is figured in the white on the Continent. So that it is probable that as much is figured abroad as at home, and this principally on account of wages being lower there than here, notwithstanding the low rate of embroidery earnings in this Country. This foreign embroidery is chiefly done in Belgium, Saxony, and, until recently, in Poland. The exports of bobbin net are in great part to Hamburgh, for sale at home, and at Leipsic and Frankfort fairs, Antwerp, and the rest of Belgium, to France by contraband, Italy, and North and South America. Though a very suitable article, yet the quantity sent Eastward of the Cape of Good Hope has hitherto been too trifling for notice. Three-eighths of the whole production is sold unembroidered at home, the remaining one-eighth of the half kept in this Country is embroidered, and increases the estimated value as under, *viz.*

Embroidery on power net increases value £131,840, and is ultimately worth £553,715.

Embroidery on hand net increases value £1,205,860, and is ultimately worth £2,583,985.

Embroidery on fancy nets increases value £78,750, and is ultimately worth £105,000.

Embroidery on silk net increases value £109,375, and is ultimately worth £175,000.

Total embroidery wages and profit, £1,525,825.

Ultimate total value, £3,417,700.

From this it appears that, in the operations of this trade, which had no existence twenty years ago, £150,000 original cost of cotton and silk becomes, when manufactured, of the ultimate value of £3,417,700 sterling.

There are about seventy houses engaged chiefly in embroidering goods, and as many engaged in the preparation and sale of plain goods principally. The cash paid to small owners for the purchase of hand nets about equals the amount of capital created by the credit given to this market by power-net manufactures.

As to weekly wages paid, the following is hazarded on the judgment of those conversant with the respective branches, *viz.*

In fine spinning and doubling, adults 25s., children 7s., work twelve hours per day.

In bobbin-net making, men working machines, 18s. apprentices, youths of fifteen or more, 10s.; by power fifteen hours, by hand from eight to twelve hours, according to width.

In mending, children 4s., women 8s., work from nine to fourteen hours, *ad libitum*.

In winding, threading, &c., children and young women 5s., irregular work according to the progress of the machines.

In embroidery, children seven years old and upwards 1s. to 3s., work ten to twelve hours; women, if regularly at work, 5s. to 7s. 6d., twelve to fourteen hours.

As an example of the effect of the wages of lace, embroidery, &c., it may be observed, it is often the case that a stocking weaver in a country village will earn only 7s. per week, and his wife and children 7s. to 14s. more at the embroidery frame.

Mechanical Processes.

Manufac-
tures.

On the subject of health, fine spinning and doubling is not so injurious as is generally supposed. In bobbin-net power factories, the rooms are not hot and confined, the lads are healthy, having, like men, only to superintend, not to work the machines. To interfere with them by any legislative act seems unnecessary, and therefore injurious in its effects.

In hand-machine labour, which is heavy compared with that of stocking and most other machines, two hands work most of the wide machines in four-hour shifts. Their health has hitherto been good, but owing to the late depression of twenty-five per cent. in wages, and thirty-five per cent. in prices, increased exertion is made by the hands, and it is very probable that further depression in wages will cause material deterioration in the general health of the hand workmen, especially those engaged in wide machines.

The principal part of the hand machines are worked in shops, forming part of or attached to private houses. The subjoined list will show the ownership and kinds of machinery now at work in the bobbin-net trade.

The health of the lace embroiderers, owing to their leaning over the running or embroidering frame, is frequently impaired; for where there is predisposition to pulmonary diseases or indigestion, it is brought into activity, and slight distortion of the body is common amongst those regularly and closely employed. It is the concurrent testimony of all those authors consulted, that, the tender age of female children when they begin to be employed being considered, the hours of working are too long; however, being domestic employ, and voluntary on the part of the parents of the children in question, or of the young persons themselves, it is difficult to interfere.

The following shows the change from 1831 to 1833.

Capital employed in spinning and doubling the Yarn.

Fixed capital in 35 spinning and 24 doubling factories, £460,000 spinning, £255,000 doubling spinners	£715,000
Floating capital in spinners' and doublers' stock, and necessary sundries	200,000
	£915,000
Deduct one-sixth employed for foreign bobbin-net trade	155,000
Total capital employed in spinning and doubling for English bobbin-net trade	£760,000

Capital employed in Bobbin-net Making.

Fixed capital in 25 factories, principally for power machines	£85,000
Fixed capital in 1100 power machines, averaging 11-quarter wide	170,000
Fixed capital in 3900 hand machines, averaging 9-quarter wide	267,000
Floating capital in stock	£
on hand-power owners	150,000
Floating capital in stock	£
on hand owners	250,000
	400,000
	922,000
Capital in embroidering, preparing, and stock	250,000
Total capital employed in trade	£1,932,000

Mechanical
Processes.

The following number of hands are employed:

In spinning, adults 4800, children 5500	10,300
In doubling, adults 1300, children 2000	3,300
	13,600
Deduct one-sixth employed for foreign demand	2,300
	11,300
In power-net making, adults 1500, youths 1000, children 500, women and girls in mending 2000	5,000
In hand-machine working, small machine owners 1000, journeymen and apprentices 4000, winders 4000, mending 4000	13,000
Mending, pearling, drawing, finishing, &c. ...	30,000
In embroidering, at present very uncertain, probably about	100,000
Total of hands employed	159,300

Value of the raw Material when imported, and of the Goods manufactured therefrom.

Amount of Sea-island cotton annually used 2,387,000 pounds, value before the late advance £179,000, but now worth £224,000. This is manufactured into yarn, weighing 1,532,000 pounds, value £766,000. But of this quantity 262,000 pounds are sent abroad, leaving 1,270,000 pounds; value before the advance £635,000, and since the advance worth £680,000. This yarn (inclusive of about £10,000 worth of thrown silk) is worked up into

5,645,000 yards of hand lever quilling net, averaging, fine 11-point, at 1s. 3d. per square yard, £352,815.
2,207,000 yards of hand circular quilling net, averaging, fine 11-point, at 1s. 3d. per square yard, £137,935.
6,622,000 yards of hand circular plain net, averaging, fine 12-point, at 1s. 6d. per square yard, £496,650.
4,580,000 yards of hand rotary plain net, averaging, common 11-point, at 1s. per square yard, £229,000.
10,905,000 yards of power plain net, averaging, common 11-point, at 1s. per square yard, £545,250.
562,000 yards of fancy net, at 2s. 6d. per square yard, £70,250.
250,000 yards of silk net, at 1s. 6d. per square yard, £18,750.

Total square yards 30,771,000, annual produce of English bobbin net, of the present value, £1,850,650.

Two years ago there was much fine yarn on hand, and many mills were then standing, or only worked three or four days a-week; all these, and many others, are now, 1833, in full occupation, their production being regularly absorbed by the actual demand, for there are now no stocks of fine yarns here, or on the Continent; and while an advance has taken place in coarse yarns equal to the rise in the price of cotton wool, none has yet taken place in fine yarns in the market.

By comparing this calculation with that of 1831, when 23,400,000 square yards, the then annual produce, were worth £1,891,875, it will be seen that, while there is a difference in favour of the machine owners and workmen, in the smaller proportion of quillings to plain nets now made, and in the advantageous use of much new and improved machinery, yet, on the other hand, they are producing 7,000,000 of square yards per annum more than at that time, for

Manufac-
tures.

about the same amount of wages and profits; the number of cotton now used being on an average as fine, and its price as high, at the period when that calculation was made. The average fall in the price of bobbin net has been twenty per cent. It is probable that about £550,000, or little more than one-third of what was paid in 1831, may have been paid for English embroidery during the last twelve months. Since that period the embroidery put on bobbin net, both at home and abroad, has been of much less expensive quality than heretofore, as well as at greatly reduced wages, which will account for part of the great diminution here stated, and decreased demand explains the rest. Foreign embroidery on bobbin net is annually on the increase, and likely to continue so.

Of late, three-fourths of our production have been exported, and chiefly in the plain state. The American trade, which has much increased, is supplied entirely in the white. Quillings are sent to the North of Europe in the white, as are also the principal parts of wide nets sent to those markets. A large quantity of wide net is sent into Belgium and into France in the unbleached state. We have almost entirely ceased to export quillings into France, as they make an immense quantity themselves. Recently, increased impediments have been thrown in the way of the introduction of bobbin net into France, as also of the English yarn, the latter to satisfy the French spinners, the former the makers of net. The demand for quilling from Germany has also materially declined, and many houses are giving up dealing in the article.

English Bobbin-net Machinery.

Hand levers, 5 and 6-quarter, 500; 7-quarter, 200; 8-quarter, 300; 10-quarter, 300; 12-quarter, 50; 16-quarter, 30; 20-quarter, 20.	
Hand rotary, 10-quarter, 100; 12-quarter, 300.....	1,800
Hand circular, 5 and 6-quarter, 100; 7-quarter, 300; 8-quarter, 400; 9-quarter, 100; 10-quarter, 300; 12-quarter, 150	1,350
Hand traverse, pusher, and straight bolt, average 5-quarter	750
Total hand machines	3,900
Power 5, 6, and 7-quarter, 90; 8-quarter, 350; 10-quarter, 280; 12-quarter, 350; 16-quarter, 30	1,100
Total number of machines ...	5,000

The wages paid in fine spinning are, for adults, from 8s. to 40s., and perhaps may average 17s. per week; children from 2s. 6d. to 7s., averaging about 5s. In doubling, adults from 8s. to 30s., averaging about 12s.; children from 2s. 6d. to 7s., averaging about 4s. 6d.

In bobbin-net making, men 18s., apprentices 10s., boys 5s. In mending, winding, threading, &c., children 4s., women 8s. In embroidering, children 1s. to 2s., women 3s. to 5s. per week, working twelve to fourteen hours. During the last two years, an extraordinary depression has taken place in the demand and wages paid for embroidery, chiefly arising from competition with Belgic and Saxon embroidered goods. Wages are lower in those Countries than they have been here, though our good hands were reduced to 2s. 6d. or 3s. a week, for women's wages. Many have left the business in despair, and a considerable reaction has taken place, so

that hands are now scarce at the rate above quoted. It is difficult to ascertain with any exactitude the number at present employed. Mechanical Processes.

Wages were reduced in 1830 and 1831, say twenty-five per cent., or from 24s. to 18s. a-week, and machines had increased in the same time one-eighth in number, or from 4000 to 4500, and one-sixth in capacity of production. It has also been stated to be deserving the serious notice of all proprietors of existing machines, that new ones were introduced into the trade, of such power of production as must still more than ever depreciate the value of their property, have a direct tendency to sink the small owners into journeymen, and either greatly increase the labour or depreciate the wages of the workmen. The machines that have since been built, if worked by three men, in six-hour shifts, or eighteen hours per day, would each turn off 20,000 square yards of good net per annum. The result then predicted has actually occurred; the wages per week have been much lowered, although the weekly earnings are now about the same as in 1831. The inferior machines are single-handed, and the journeymen are working either wider or speedier machines than heretofore, so as to produce probably a fourth more net.

Such was the state of this important trade in 1831 and in 1833; and although it is much to be regretted that the wages of those employed do not appear to keep pace with the increased demand, yet the value of the manufacture, looking at the immense sums paid in wages altogether, cannot but be considered very important, particularly when it is considered that only twenty-five years back it had not sprung into existence.

Hosiery.

(1046.) Hosiery is a term originally applied to express the article of dress which covers the feet and legs, but it now is understood to comprehend generally all articles made by knitting, or with a frame producing a similar stitch. The Art of knitting is by no means of ancient date; the hose or stocking having been, up to the time of Henry VIII., made of milled cloth by tailors. It seems probable also, that the first knit stockings were of silk, although the same process soon became common with other materials. At all events, there are but slender grounds for placing the Art of knitting earlier than the commencement of the XVIth Century; and there is sufficient evidence that, up to nearly the beginning of the XVIIth Century, cloth hose, made by tailors, were not uncommon. It is stated by Dr. Howell that Henry VIII. occasionally received knit silk stockings from Spain; that Edward VI. was presented with a pair of long silk stockings by his merchant, Thomas Gresham, which present was taken great notice of; that Queen Elizabeth received a like present from her silk woman, Mrs. Montague, and that she never after wore any other. At the same time other proofs are given that, however novel the Art of knitting might be in the beginning of the XVIth Century, it was by no means uncommon towards the end of it; for it is recorded that, about the year 1570, only nine years after Elizabeth had received the aforesaid present, on her visit to the city of Norwich, several female children appeared before her, "some of whom were spinning worsted yarn, and others knitting it into yarn hose, or stockings."

It would be uninteresting and unprofitable to pursue an inquiry relative to the Art of knitting, or to attempt

Manufac-
tures.

to describe in words what is so commonly practised and so well known, although no longer for any thing more than mere amusement; for the Art of stocking weaving enables the workman to produce his article so quickly, that knitting, as a means of profitable employment, has been long laid aside, except in such places as are far remote from the localities of other manufactures, which generally furnish to women and children a much more active and desirable occupation.

Invention
of the
stocking
loom

Stocking frame or stocking loom.—It is observed by Beckmann, in his *History of Inventions*, that the stocking loom is worthy of particular admiration, as it was not, like many great discoveries, the result of accident, but the reward of well-applied talent and genius. It is an exceedingly complicated machine, consisting, according to the quality of the article, of many hundreds, even thousands, of moving parts, which in an instant almost can make a hundred or two hundred meshes, without requiring much skill or labour on the part of the workman. It is also remarkable that it so soon followed the Art of knitting, and that but little improvement was made on the original machine for a period of about 170 years. There is also another peculiarity attending the invention of the stocking loom, viz., that there seems to be comparatively little or no dispute concerning its original author, or the period of its introduction, this honour being almost universally given to William Lee, in the year 1589.

It appears by Beckmann, *History of Inventions*, vol. iv., that, under the administration of Cromwell, the stocking knitters of London presented a petition in which they required permission to establish a guild. In the petition they gave the Protector an account of the rise, progress, and importance of their Art or trade; and there can be no doubt that this document, which is well written, contains the oldest authentic information in regard to this invention, which was then scarcely fifty years old. On this account every thing must have been fresh in the memory of those by whom it was drawn up, every circumstance could then be easily examined, and the petitioners must have been sensible that any misrepresentation they might make could be readily contradicted. An account of this petition is given by Deering in his description of Nottingham, where the loom was first employed, and where it has since enriched many families, and from which place the use of it has spread throughout almost every part of England and of Europe. From these details of Deering it appears that the real inventor

by William
Lee, in
1589.

was William Lee, whose name in the petition was spelled Leea, a native of Woodborough, in Nottinghamshire, a village about seven miles distant from Nottingham. He was heir to a considerable freehold estate and a graduate of St. John's College, Cambridge. It is reported that, being enamoured of a country girl, who during his visits paid more attention to her work (which was knitting) than to her lover, he endeavoured to find out a machine which might facilitate and forward the operation, and by these means afford more leisure to the object of his affections to converse with him. In the Stocking Weavers' Hall in London is an old picture, in which Lee is represented pointing out his loom to a female knitter who is standing near him, and below it is an inscription with the date 1589. The inventor instructed his brother James in the use of the loom, and took apprentices and assistants, with whom he carried on business for some years at Calverton, a village five miles distant from Nottingham, from which circumstance this village has been erroneously

considered as the place of his birth. He showed his work to Queen Elizabeth, and requested of her some support or remuneration; he, however, obtained neither, but was impeded rather than assisted in his undertaking. Under these circumstances, Lee accepted an invitation from Henry IV. of France, who had heard of this invention, and promised to give a handsome present to the author. He therefore carried nine journeymen and several looms to Rouen, in Normandy, where he worked with great approbation; but the King being assassinated, and internal commotions taking place, Lee fell into great distress and died soon after in Paris. Two only of his people remained in France, who were living when the above-mentioned petition was presented to Cromwell; the other seven returned to England, and these, with a person named Aston, who was one of Lee's apprentices, laid the foundation of the stocking manufacture in Nottingham, London, and other parts of England. The number of masters increased so much in London in the course of fifty years that they wished to be united into one guild, as above stated, which, however, for some reasons not known, was refused by Cromwell; but in 1663 they received Letters Patent, which gave them certain privileges to the extent of ten miles round London.

Mechanical
Processes.

In the year 1614, the Venetian Ambassador persuaded an apprentice, Henry Mead, by a promise of a present of five hundred pounds, to go with a loom to Venice for a stated time, and to teach the use of it in that State. Mead met with a favourable reception in the city, and was much admired; but the loom becoming deranged, and no person in Venice being able to repair it, when the time of his agreement was expired he returned to England. The Venetians had not sufficient resolution to continue the attempt, and sent the damaged loom, together with some bad imitations of it, to England, where they were sold for a mere trifle.

This account, which is contained in the petition above referred to, is contradicted by some Italian authors; it is, however, very consistent with the known difficulty of making and repairing the stocking frame even to the present day. The number of moving parts is so great, and the compass of their action so small, that the slightest bending of the needles, or the slightest derangement, renders the whole machine unserviceable; a circumstance which has given rise to a class of workmen called *setters-up*, whose business is to put in order any frame which, by accident or ill usage, has been deranged: these are not the frame smiths; but have about the same relation to them that the tuners of the piano-forte have to the makers of that instrument.

The Italian writers, however, deny this statement, and maintain that the Ambassador above referred to brought two stocking weavers to Venice, that he placed under them four apprentices, and when these two went back to England he sent with them a boy who returned to Venice well instructed in the Art, and who continued to carry on business there with great success; and that Giambaptista Carli of Gerona, a smith who worked in steel, saw the loom at Venice, which had been made after the model of those brought from England and sold to Francesco Alpruni of Udino; that, in a short time, he made other frames; and that a great many stockings were manufactured there and sent for sale, chiefly to Austria. But in consequence of the poverty thus brought upon the Venetian stocking knitters, an order was issued that Carli should make no

Manufac-
tures.

more looms; and this productive branch of business at Udino was, in consequence, so much deranged that the masters removed with their looms to Gradisca, where the inhabitants of Udino were obliged to purchase such stockings as they had occasion for. It appears further that, some years after this, one Abraham Jones carried the stocking weaving to Amsterdam, but that, in a short time, he and his assistants were carried off by a pestilential disease, and that these looms were returned to England, no one in Amsterdam knowing how to use, and much less how to repair them.

French
claim to the
invention.

We have said the honour of this discovery was without dispute due to Lee, but it ought rather to have been said that it was undoubted, but not entirely undisputed; and that we may not be supposed to take a partial view of the case, it may be well to conclude our sketch with a quotation from Beckmann, who observes, after stating many of the preceding facts, "It appears to me, therefore, proved beyond all doubt, that the stocking loom was invented by William Lee about the end of the XVIth Century; and this is admitted by some French writers, such as Voltaire and the Editor of the *Encyclopédie*, whom the author of the *Encyclopédie Méthodique*, however, finds fault with. Other French writers, who are the more numerous party, wish to ascribe the honour of this invention to one of their own Countrymen, but the proofs they bring are so weak that they scarcely deserve any notice. Savary is perhaps the first person who ventured to support this instance of Gallic vanity; at all events, he is quoted by the more modern writers as their authority when they wish to contradict the English.

"According to his account a Frenchman, of whom, however, he knows nothing further, invented the stocking loom, but not being able to obtain the exclusive privilege of using it in his own Country went to England. The utility of it being soon discovered there, it was forbidden, under pain of death, to carry the loom, or a model of it, out of the Kingdom. But another Frenchman, respecting whom he is equally ignorant, having seen the loom, the form of it made so strong an impression on his mind that, on his return, he copied it exactly, and from this loom all the others made in France and Holland were constructed. Savary adds, 'Did the invention belong to the English, who are accustomed to pay due honour to those who discover useful things, they undoubtedly could tell the name of the inventor, which, however, they are not able to do.' It is very strange that this should be written by a Frenchman, who himself did not know the name of the French inventor, or of the person who carried back the invention. No order to prevent the exportation of the stocking loom was issued in England so early as Cromwell's time, otherwise it would certainly have been mentioned in the petition presented to him. It was not till the eighth year of the reign of William III., that is, 1696, when looms were every where common, that the exportation of them was forbidden, probably because the best were made in England, and it was wished that the gradual improvement in them should be kept a secret.

"Some have endeavoured to give an air of probability to the above assertion of Savary, by the relation of an apothecary in the Hôtel Dieu at Paris. This person is said to have declared that the inventor was a journeyman locksmith, in Lower Normandy, who gave a pair of silk stockings, his own workmanship, to Colbert, in order that they might be presented to Louis XII.; but as the *marchands bonnetiers*, who

dealt in articles knit after the old manner, caused several of the loops of these stockings to be cut by some of the servants at Court, whom they had bribed for that purpose, they did not meet with approbation. The inventor was so hurt by this disappointment that he sold the loom to an Englishman, who died an old man in the Hôtel Dieu, where the apothecary became acquainted with him. It was necessary to expose the lives of many workmen, and even some men of learning, in order to bring back the loom to France. Romé de la Platière adds that he heard at Nismes that, in the time of Colbert, a person of that place, named Cavallier, carried the first loom to France, and that in the course of fifty years the number of them in that town and neighbourhood increased to some thousands. It appears much more probable, however, as Savary asserts, that the stocking manufacture was established at the castle of Madrid, in the *Bois Boulogne*, near Paris, in the year 1656, under the direction of John Hindres." Beckmann, *History of Inventions*, vol. iv.

It must be seen, however, after all, that the whole of this French history is void of any written document or authority, and is at variance with itself, and that it in nowise substantially militates against the claims of the Englishman, William Lee, who, we think, there can be no reason to doubt, was the actual and original inventor.

The great ingenuity displayed in the invention of this excellent machine has induced us to enter at considerable length into its original discovery, which we could do with the greater propriety, as it seems to have undergone but trifling alteration for nearly 170 years, when the first important improvement was made by Jedediah Strutt, who, in 1759, obtained his Patent for the Derby ribs. From this epoch the most extraordinary efforts were made to vary and add to the mechanism of the stocking frame, so as to adapt it to the production of fancy work and imitations of pillow lace. These were at first very imperfect, but led, in the course of the next half century, to the invention of the point-net, pin-net, warp-net, and finally to the bobbin-net machines. About 1776, Horton patented his knotted frame, and soon after this the twilled and elastic machinery was invented. We shall here consider the history of the stocking frame as complete, and endeavour to give to the reader the best idea we can of its mechanism, availing ourselves in this respect of the descriptions by Mr. J. Duncan and Mr. Farey; and for the statistics of the trade we are indebted to an excellent article on the subject by W. Felkin, Esq.

(1047.) *Description of the stocking frame.*—The nature of this machine, and its operation, will be best described by first referring to fig. 1, plate lxxvii., which represents a single thread formed into a number of loops or waves by arranging it over a number of parallel needles, as shown at R, R; these are retained, or kept in the form of loops or waves, by being drawn or looped through similar loops formed by the thread of the preceding course of the work S. The fabric thus formed by the union of a number of loops is easily unravelled, because the stability of the whole piece depends upon the ultimate fastening of the first end of the thread; and if this is undone, the loops formed by that end will open and release the subsequent loops one at a time till the whole is unravelled and drawn out into the single thread from which it was made. In the same way if the thread of a stocking piece fails or breaks in any part, or a stitch drops, as it is called, it immediately produces a hole, the extension

Mechanical
Processes.

Description
of the
stocking
frame
or loom.
Pl. lxxvii.
Fig. 1.

Manufac-
tures.

of which can only be prevented by fastening the end. It should be observed that the stitch we have endeavoured to represent is the common plain stitch; there are several others, but the above is the foundation of them all.

Fig. 2, 3.

The wires represented in fig. 1 are what are called the needles; they are made of iron wire of the shape represented in fig. 2, 3, being hooked or barbed at the end, and the returned ends made very fine and delicate. Under the return there is a small cavity or groove punched or sunk in the stem, as seen in fig. 3, of sufficient depth to receive the point of the needle when an adequate pressure is applied upon the hook to bend the barb down. This thus becomes a closed eye, and if a thread is looped over the wire or stem of the needle, and drawn forward while the barb is thus closed, it will draw over the barb of the needle and come off at the end of it; but if the thread is drawn forward while the barb is open, it will be drawn under the hook and be thus detained, as shown in fig. 1. This circumstance must be particularly attended to, as the principal action of the machine depends upon it. The depression of the barb of the needle is produced by the edge of a presser bar, which is extended horizontally over the whole length of the needles, and is acted upon by pressing the foot on the middle treadle of the machine.

Fig. 4, 5.

Such being the form of the needles, they are now to be fitted to the frame, in order to which they are cast into tin sockets or *leads*, as they are called, which is done by placing the needles in an iron mould, which opens and shuts by means of a joint, and pouring in tin while it is in a state of fusion. The form of the needle, when complete and fitted to its place in the frame, is represented at fig. 4, which is a profile section of the needle bar exhibiting one needle. In this figure F represents a section of the presser bar above mentioned, G is the needle, and H a section of the needle bar, on the front part of which is a small piece of iron called the verge, to regulate the position of the needles. When placed upon the bar resting against the verge, another plate of iron, generally lined with soft leather, is screwed down upon the sockets or leads in order to keep them all fast. This plate and the screw are shown at I. When the presser bar is forced down upon the barb, the needle, as before stated, is shut, and when the presser rises the barb rises or opens by its own elasticity. The needles or hooks, being all properly fitted, the next part of the machine which requires description is that for forming the loops. This consists of two parts. The first of these, which sinks between every second or alternate needle, is represented at O, fig. 5, which is a transverse section of the frame, and is one of the most important parts of the whole machine. It consists of two moving parts called *jacks*, being a succession of horizontal levers moving upon a common centre, one only of which can be represented in fig. 5; but their action is seen more distinctly from the perspective view, fig. 6, on an enlarged scale. The jack shown in fig. 5 extends horizontally from O to I, the centre of motion being at R. On the front or right-hand part of the jack at O is a joint suspending a very thin plate of polished iron, termed a *sinker*, and one of these jacks and sinkers is allotted to every alternate needle in the frame; these also will be best seen in fig. 6. The other ends of the jack, seen in fig. 5, 6, are tapered to a point, and when the jacks are in their horizontal position, they are secured by small iron springs *k k*, fig. 6, each spring having a small obtuse-angled notch to receive the point of the jack, against which it presses by its own elasticity. The standards

Mechanical
Processes.

upon which the jacks move are called combs, and consist of pieces of flat smooth brass parallel to and equidistant from each other. The cross bar, which contains the whole, is of iron with a perpendicular edge or rim on each side leaving a space to receive the bottom part of the comb; these are then fixed in the bar with a flat piece of brass, called a counter comb, between each, to fix and preserve their distance from each other; the counter combs are exactly the same shape as the combs, but have no tails. When both are placed in the bar it is luted with clay so as to form a mould, into which melted tin is poured, and the counter combs being removed, the combs remain at exactly equal distances and are united with the jacks by a common axis passing through holes in each, as seen in fig. 6.

Fig. 6, 7, 8.

We have now to describe what are called the *lead* sinkers, those above spoken of being called *jack* sinkers, from their being attached to the movable levers or jacks; the lead sinkers are exactly like the former, but are differently attached, being all fixed to one bar, called the sinker bar, marked P in fig. 7. These are placed alternately between the jack sinkers, and between each sinker throughout is one needle.

We have already explained the action of the small spring which supports the jacks in their horizontal position, and by referring to fig. 6 it will be seen that when the jack sinker is elevated, so that its nip *f* is above the level of the needle ready to receive the thread, the end of the tail is received in the notch of the spring *k*, which retains it in that position; but at the same time a small force applied beneath the tail of the jack to lift it up will depress the nip *f* of the jack sinker between the needles. It will be seen that the office of the sinkers is to form the loops shown in fig. 1, but it is obvious these could not be all formed at once without danger of destroying the thread by the friction to which it would be exposed; and the means of avoiding this evil is by a very ingenious contrivance which we must next explain. A straight iron bar *l*, fig. 6 and 8, called the slur bar, is extended beneath all the jacks, and upon this a piece of metal *m*, called the slur, travels with rollers to reduce the friction; it is drawn by a line extended on each side, and conducted over a pulley at each end of the bar *l* to be carried round the slur wheel *L*, fig. 5. An alternate motion is given to this wheel by means of treadles worked by the weaver; and by this means the slur is made to travel backwards and forwards, thus depressing only one loop at a time, but in very rapid succession, and the jacks will be retained in the position given to them by the spring *k*. When all the jack sinkers are thus depressed, a loop of thread will be formed between every other pair of needles. The workman then depresses the lead sinkers, and their nips carry down the thread between the remaining needles in loops all at the same time, so that there is now a loop between every needle in the frame, the jack sinkers being made to rise up as much as the lead sinkers are depressed, making thus all the loops throughout of the same size, the jack sinkers in the first instance forming them of double the depth required.

These loops are now to be carried backward upon the needles represented at S, fig. 1, so as to come below the arch or openings of the sinkers, fig. 6, which open part is on purpose to admit the loops last made upon the stems of the needles, quite detached from the action of the sinkers, by which, therefore, may be made a new course of loops independent of the former. It remains

Manufac-
tures.

now to show how the loops are put back upon the needles. This is done by lifting up the hand bar till the points of the sinkers rise above the needles; the bar is then drawn forwards to advance the sinkers till the thread is behind the points *t*, then depressing these and pushing back the hand bar, the points *t* carry back the loop upon the stem of the needle, as above stated, under the arch of the sinker. The first row of loops being thus disposed of, the frame of sinkers is restored to its original position, and a second row of loops is formed on the stem of the needles by a repetition of the same process; and this row is now to be brought forward so as to be under the barbs or hooks of the needles, which is done by drawing the hand bar forwards till the thread is in its required place beneath the hook. By the action of the treadle the presser bar is made to act upon the barbs of the needles to close them with the thread within them. The first formed loops are now brought forward upon the closed needles, and thus pass over the end of the needle, and the new formed loop within them. By this means the loops of what was the upper or last course of the finished work become secure from unravelling, and the loops under the barb now become the upper course, and are made to occupy the place of the former, and thus, in succession, the several rows are rendered one entire piece. The loops *S, S*, fig. 1, represent only a single line of loops; the reader, however, must consider them as the upper row of the work done in proper connection with it.

We are afraid the above description will give but an imperfect idea of the operation of this exceedingly ingenious piece of mechanism; but to have rendered it more intelligible, or, at least, so much so as to have illustrated its entire action, would have occupied more space and more figures than we could bestow upon it in a Treatise of this kind which embraces so many different processes and machines. We trust, however, that a tolerably general idea of its operation may be acquired from what has been stated. The description we have attempted relates only to the plainest work; a different combination is required for ribbed, plated, and fancy work, which, with the exception of the ribbed stocking frame, we must pass over, for the reasons above stated.

Ribbed
stocking
frame.
Fig. 9, 10.

(1048.) *Ribbed stocking frame*.—The frame which, next to the common frame, is most extensively in use, is that employed for working stripes or ribbed stockings. In principle it does not differ from the common frame, and not greatly in construction; the foregoing general description will apply therefore equally as well to this as to the former; that part, however, by which the ribs or stripes are formed is entirely an addition, and to the application of it, it may be proper to pay the chief attention. See fig. 10, which is a profile elevation. The principle of weaving ribbed hosiery resembles considerably the weaving of that kind of cloth called tweeling, for the formation of stripes, with some variations arising merely from the different nature of the fabric. In cloth weaving, two different kinds of yarn, intersecting each other at right angles, are employed; in hosiery only one is used: in the tweeling of cloth, such as dimity, cotton, kerseymere, or woollen manufactures, the stripes are produced by reversing the yarns; in hosiery, where only one yarn is required, a similar effect takes place by reversing the loops; but in order to give this effect, a second set of needles is placed upon a vertical frame so that the bends

of the hooks may be nearly under those of the common needles. The needles are cast in tin moulds, as in the common machine before described, but more oblique, or bevelled towards the points to prevent any obstruction in their working; they are also screwed to a bar of iron, generally lighter than the other, and secured by means of plates; this bar is not fixed, but has a pivot in each end, by means of which it has free motion on the pivots. Two frames of iron support the bar; that in which it oscillates being nearly vertical, but inclining towards the other needles. Fig. 10, which is a profile elevation, will serve to illustrate the relative position of one bar to the other, the lower or horizontal frame, the ends only of which can be seen in fig. 9, under *aa*; these are shown in profile, fig. 10, marked *d*; the vertical frame at *a* is attached to this by two centre screws, which serve as joints for it to move in. On the top of this frame is the ribbed needle bar at *f*, in fig. 10; one needle is also represented in fig. 10 at *f*; *g* is a small presser to shut the barbs of the rib needles, in the same manner as the large one does those of the frame; *h* is one of the frame needles, to show the relative position of the one set to the other; the rib bar is not filled with needles, since it will be seen they are only required where ribs or stripes are to be formed, the intervals being filled up with blank leads, that is to say, the sockets are the same shape as the others but without needles, being merely designed to fill the bar and preserve the spaces. Two small handles are suspended from the needle bar by which the oscillatory motion upon the centre is given; the up-and-down action is communicated to this machine by chains, which are attached to iron sliders below, and which are wrought by the hosier's heel when necessary; the pressure takes place partly by the action of the smaller presser, and partly by the motion of the needles in descending; there is also a small iron slider placed behind the rib needles, which rise as they descend and serve to free the loops perfectly from each other.

In the weaving of ribbed hosiery, the plain rib courses are wrought alternately; when the plain is finished, the rib needles are raised between the others, but no additional yarn is required; the rib needles, intersecting the plain ones, merely take up the last thread, and, by again bringing it through that which was on the rib needle before, give it an additional looping, which reverses the line of chaining, and raises the rib above the plain intervals, which have only received a single knitting.

In concluding this article, the following statistic statement of the hosiery trade in 1833, we have no doubt, will be interesting to the reader.

(1049.) Worsteds hosiery is chiefly made in Leicester-shire; silk hosiery in Derby and Nottingham; and cotton hosiery throughout the Counties of Nottingham and Derby, at Hinckley, and at Tewkesbury. The analysis furnished by Blackner, in 1812, may be perhaps modified as follows, so as to show the kinds and qualities of goods which the frames were, in 1833, employed upon, *viz.*:

Plain cotton, 14 to 22 gauge, 1600; 24 to 28 gauge, 1600; 30 to 34 gauge, 2790; 36 to 60 gauge, 1600 frames	7,590
Gauge, 600; gloves and caps, 1000; drawers, 500; sundries, 560	2,660
Wide frames, making cut-ups and various other kinds	6,030
Carried forward	16,280

Mechanical
Processes.

Statistical
statement
of the
hosiery
trade.

Manufac-
tures.

	Brought forward	16,280
Worsted 12 to 20 gauge, 4400; 22 to 26 gauge, 3600; 28 to 34 gauge, 1450 frames		9,450
Angola, 1350; lamb's wool, 1900; shirts, 500 frames		3,750
Wide frames with worsted goods		520
Silk, 2300; gloves, 350; and knots, 350		3,000
Total of frames		33,000

The following statement, it is believed, presents a sufficiently accurate approximation to the annual amount in quantity and value of goods manufactured in this trade to answer all practical purposes. Each narrow cotton frame produces about 40 dozen of hose a-year, if of women's size; wide cotton frames 300; narrow worsted 75; wide worsted 150; and silk 30. There are

10,300 frames making fashionable cotton hose which produce 420,000 dozens, and consume 880,000 pounds of cotton yarn valued at £73,000, wages for making which £220,000, and finishing £32,000, total £325,000.

6000 frames making cut-ups, &c., produce 1,960,000 dozens, and consume 2,940,000 pounds of cotton yarn valued at £172,000, wages for making which £285,000, and finishing £98,000, total £555,000.

9500 frames making fashionable worsted produce 710,000 dozens, and consume 2,840,000 pounds of worsted valued at £284,000, wages for making which £215,000, and finishing £41,000, total £540,000.

1000 frames making cut-ups, &c., produce 100,000 dozens, and consume 400,000 pounds of worsted valued at £40,000, wages for making which £30,000, and finishing £10,000, total £80,000.

1300 frames making angola produce 95,000 dozens, and consume 332,500 pounds of worsted valued at £45,000, wages for making which £40,000, and finishing £19,000, total £104,000.

1900 frames making lamb's wool produce 135,000 dozens, and consume 639,500 pounds of worsted valued at £80,000, wages for making which £50,000, and finishing £16,000, total £146,000.

3000 frames making silk produce 90,000 dozens, and consume 105,000 pounds of silk valued at £120,000, wages for making which £108,000, and finishing £13,000, total £241,000.

Total 33,000 frames, which produce 3,510,000 dozens, using 8,137,000 pounds of materials of £814,000 value, to which add wages £948,000, and finishing £229,000, total £1,991,000.

According to this calculation, the value of the cotton hosiery annually made is £880,000; that of worsted, &c. is £870,000; and that of silk is £241,000. To produce these goods it is probable that 4,584,000 pounds of raw cotton wool, value £153,000, are used, and 140,000 pounds of raw silk, (two-fifths China and three-fifths Novi), value £91,000, also 6,318,000 pounds of English wool, value £316,000. The total original value of the materials used is, therefore, £560,000, which, it appears, become of the ultimate cost value of £1,991,000 in this manufacture. There are employed in the various processes as follows, viz.,

In cotton spinning, doubling, &c.	3000 persons;	
worsted carding, spinning, &c.	2500;	
silk winding, throwing, &c.	1000	6,500
In making stockings	13,000 men, 10,000 women, 10,000 youths; women and children in seaming and winding, &c.	27,000
		60,000

Carried forward 66,500

Brought forward	66,500
In embroidering, mending, bleaching, dyeing, dressing, putting up, &c. probably about . . .	6,500
Total persons employed	73,000

Mechanical
Processes.

The capital employed in the various branches of the trade may be thus estimated, taking the machinery and frame at neither their original cost nor actual selling price, but at their working value, and the stocks of hosiery on an average of years.

	£.
The capital in mills and machinery for preparing cotton is	70,000
Ditto worsted, &c.	52,000
Ditto silk	18,000
Fixed capital in mills, &c.	140,000
Ditto in frames	245,000
Total of fixed capital	£385,000
In wool and yarn in process and stock . . .	85,000
Ditto worsted, &c.	150,000
Ditto silk	35,000
Floating capital in spinning, &c.	£270,000
Capital in narrow cotton frames	62,000
Ditto wide	60,000
Ditto in narrow worsted frames	76,000
Ditto in wide	11,000
Ditto in silk frames	36,000
Fixed capital in frames	£245,000
In goods in process and stock	350,000
Ditto	345,000
Ditto	85,000
Floating capital in making hose	780,000
Ditto in spinning, &c.	270,000
Total of floating capital . . .	£1,050,000

The number of frames in each locality has very materially varied since 1812. Many have been widened to make two stockings at once, and about 5000 wide frames are making cut-up work. The quantity of cotton goods made now is probably more than half as large again as at that time. Then there were about 100 hosiers at Nottingham, now there are but about 40. The number in Derby has varied little; but in Leicester it has increased. One house employs upwards of 3000 frames; a second about 2000; a third and fourth about 1800 each; a fifth 1500; and other various smaller numbers. Many of these are their own property, and an annual rent of about 40s. coarse, 50s. fine, 75s. silk, and 100s. wide frames, is paid for each by the workmen. This rent has always been considered an important source of income to the hosiers, and an important deduction by the hands: at present it amounts to about one-sixth of their earnings, and is, in fact, a payment of one per cent. weekly of the full market value of the machine. Many thousand of narrow frames have been bought at £4 or £6 a-piece, but probably all of them needed repairs, and every six or seven years further reparation, to a greater or less amount, will be needed. Some hands will wear down a frame in three years; others, however, will work them twelve or even twenty years without serious repairs, or, as it is technically called, a recruit. Each six years' recruit may cost £5; and thus 1000 frames, bought at £5 each, would

Manufac-
tures.

cost in original outlay £5000, and first recruit £5000 ; and as he would receive £15,000 in rent, if owned and employed by a hosier, he would clear £5000, or about £800 a-year ; and the next and each succeeding six years the expense would be the recruit only, and of course the amount of annual profit about £1600. Against this there is to be placed, however, the serious inconvenience and loss often sustained by the hosiers from depreciated or dead stock, created in employing these machines through flat periods, when otherwise they might be standing still. It has been seen that the frames are gradually accumulating in the hands of large manufacturers.

It is supposed that one-half of the full-wrought, and three-fourths of the cut-up, work passes from the work-people to the hosiers (it is almost entirely a domestic manufacture) through the hands of the bag-hosiers ; and as it seems quite impossible to get these men to pay entirely in money, this circumstance is felt by the hands to be a great and increasing evil ; in fact, the truck system exists in some places to a considerable extent. Wages have fallen in each branch of the framework knitting trade, during the last thirty years, about thirty per cent. The present net earnings of the worsted hands may be taken at 3s. to 6s. a-week ; of the cotton hands 4s. to 7s. a-week ; of the silk hands 6s. to 12s. a-week. Workmen making cut-up goods earn from 10s. to 21s. a-week. As this includes the youths and women employed in the frames, it is certain that, although many hands working fine gauges, or employed upon particular makes of goods, will gain more than the highest sums stated, a far greater number receive less than the lowest, which is the earnings of the great bulk of the workmen. In some periods of almost total stagnation in this trade, and when in many of those parishes which are inhabited chiefly by framework knitters the rates were becoming so large as to alarm the overseers of the poor, some of these officers bought cotton or worsted and employed stocking-makers who were without work instead of otherwise relieving them. By this plan temporary benefit occurred to the parishes and to the trade ; in one or two instances the goods were held over to a favourable season and realized somewhere about cost price ; but in the generality of cases they were sold at a great loss to the parishes or individuals who engaged in the speculation, and with much detriment to the trade, sales being most probably effected after long-continued depression. And thus, combined with the revulsion upon the supply of labour in the market by the return of the hands so employed, these sales operated to force wages and the value of stocks on hand lower than they otherwise might have been brought. These experiments shared the fate of the majority of irregular and unnatural interferences with the relation between the money and labour capital employed in any trade.

The consequence of the before described long and extreme depreciation in the value of the stocking-maker's labour are very apparent and deeply to be lamented. Most of their employers regret that which appears to them an inevitable result of the existing weight of public burdens, (bearing, as they think, peculiarly heavy upon manufacturers,) and of the surplus labour competing for employment in this as in most other manufacturing districts, and but few amongst them seem to expect any material improvement either in demand or wages. The workmen, speaking of them in the mass, are physically deteriorated ; they are mentally depressed, and too often

mechanically debased ; ill-fed, ill-lodged, and ill-clothed, with care-worn and anxious countenances, they are a class by themselves, and easily distinguishable from most others by their personal appearance ; and without attributing their extreme poverty to them as a crime, which is but their misfortune, we shall, nevertheless, be prepared to learn, what is indeed the fact, that amongst them, as amongst others similarly circumstanced, hopeless poverty is producing fearful demoralization, of all others the most certain effect of wages depressed too low, and the result most to be deplored, because the most difficult to cure.

It is supposed that during that period the hosiers' profits have decreased in an equal, if not greater, ratio than the depreciation of wages paid to those whom they employ. The respective amounts of the business done by the larger houses is of course much increased, while their numbers are materially diminished. A remarkable change has also gradually occurred during the last fifteen or twenty years. Formerly London was considered the chief hosiery mart, and a comparatively small portion of the goods was sold in Nottingham, Derby, or Leicester, most of the hosiers having houses for the sale of their goods in the metropolis : now the business is almost entirely transacted at the manufactories, or by consignments from thence abroad. Nottingham is, therefore, become the centre of the cotton hosiery trade, Derby and Leicester for the silk and worsted hosiery business respectively. The greater part of hosiery goods is yet sold for home consumption ; large quantities are, nevertheless, exported of low fashioned articles to New York, Philadelphia, New Orleans, Buenos Ayres, Lima, Rio, Lisbon, and other places ; to the West Indies and Bengal of fine cotton and silk hose ; and the export of cut-up goods has much increased of late years. As, by a recent improvement in the manner of making many of this kind of goods, more fashion is obtained with little more cost in labour, (three frames are employed upon this plan in making each stocking,) it is probable that a further enlargement of the foreign hosiery trade may, ere long, take place.

The number of hosiery frames throughout the Continent, &c. was thus stated by Blackner, in 1812, viz.,

In Paris 1000 ; Lyons 1800 ; and in twenty-two other towns in France 3955	6,855
Netherlands 520 ; Spain and Portugal 1955 ; Italy 985 ; Germany 2340 ; Petersburg, &c. 200 ; Stockholm 30 ; Copenhagen 35 ; North America 260	6,325

Total number of frames abroad 13,180

It is very probable that the number of these machines is considerably larger now than is stated above, especially in Germany, where many coarse worsted and cotton hose are made both for home consumption and exportation. Some have found their way to this Country at different times, where they are sold in bond, chiefly for America. French silk stockings are very extensively made, of good workmanship, and at a cheap rate, in the districts of Nismes, Andune, Aix, Avignon, &c., and have somewhat the preference to ours in several foreign markets. These circumstances furnish the hosiers with powerful arguments against any forced rise in wages here, however depressed they may appear. The wages of the German framework knitters are very trifling, but their cheap provisions enable them to live in tolerable comfort. Good wages are paid in Paris, and they are not low for stocking-making throughout France. Most

Mechanical
Processes.

Manufac-
tures.

of these foreign frames are very old and their insides are generally in very bad repair. The carcasses are in many cases, as indeed not a few are in England, from 100 to 150 years old. While the hosiery cotton yarn used in this Country is often of a single stand, and now rarely of more than two stands, which, when the yarn is well spun from good wool, is all that is necessary to ensure sufficient strength, yarn of five or six stands is commonly employed abroad, the stands being very unevenly spun from inferior wool. To produce good hosiery yarn is found by the English cotton spinners one of the most difficult parts of the business. As most of the foreign cotton hose are made of the coarser qualities, smuggled fine English stockings have long been more estimated and fashionable in Paris than the best silk hose. Were our thirty-six gauge or sixty-gauge cotton stockings permitted free introduction into France, the demand for them in that market would be immense. As our commercial intercourse and interchange of commodities and manufactures with France is now progressing, the manufacturers of Nottingham and their poor workmen might possibly be well repaid for any efforts they might expend in the pursuit of freedom of trade between the two Countries in this as well as other articles.

Manufac-
ture of fish-
ing-nets.
Pl. lxxvi.
Fig. 5, 6,
7, &c.

(1050.) *Fishing-nets*.—The making of fishing-nets may, at first sight, appear a very limited branch of manufacture, scarcely calling for our notice; but when again we look at the present and increasing importance of the British fisheries, it will be found that an expeditious and cheap method of manufacturing such articles is by no means an object of indifference. Several inventions of this kind exist: one was rewarded by the Society of Arts so early as the year 1796; another was proposed and rewarded by the same Society with a purse of fifty guineas in 1808; others have been invented by Mr. J. Duncan, the author of a Work on weaving, and of various articles in the *Edinburgh Encyclopædia*; but of these we can only describe one, and we consider that by Mr. John Robinson, of Edinburgh, which is the one alluded to above as having received the reward of fifty guineas, to be very simple, and best suited to give the reader a general idea of the operation. In plate lxxvi. we have given a representation of this machine, fig. 5 exhibiting it in a state ready to begin working, supported in a wooden frame. A is a beam on which the twines for the net are rolled, in number equal to the knots tied, and from which they pass through circular tubes fixed in a bar B, (shown by dotted lines through the pulley, seen better in fig. 6,) which is fixed near the circumference of two equal pulleys C, C, that turn on their axes by means of a cross treadle, with small pulleys at each end D, D, through which passes a band, one end of which is fastened on the frame at E, and the other on the pulley C. At F the band through the other pulley has one end fastened on the frame G, and, being wound round the furthest pulley C, is fastened on the under side of it, which, by the alternate action of the treadle on its axis H, moves the pulleys C, C, and circular tubes, from their situation in fig. 5 to that in fig. 7, and back again. In the centre of the pulleys C, C is fixed another bar P, with a dovetail groove, where the pirns that contain the twine are supported, (it being necessary to have two threads for every mesh, also one pirn more than there are tubes.) In a groove under the dovetail is a slider L, moved by a wire K, fixed in each end of it, having pins in it, by which it moves the pirns backwards or forwards over the notches in the bar I, so as to cast a part of the knot;

the pulleys C, C and bar B move round the bar I, as an axis, but independent of it, the bar being fastened through the pulleys to the frame; M is a movable bar (centred within two supports N, N, having two joints) with hooks, both for catching the twine at the end of the circular tubes, and, by crossing the hooks to the other side of the points of the tubes, to give the twine a turn of forming the knot, and, by raising the points of the hooks, the ends of the tubes enter between them, as shown fig. 8; and by the circular motion of the bar B, when the two pulleys C, C are turning on their centres by the foot on the end, No. 1, of the cross treadle, and until the knots so formed are close to the bar B, fig. 7, (it is then what is called a running knot,) a part of which falls into a notch cut below the level of the supporters of the pirns in the bar I; then slide the pirns over the notches that contain the twine; the knot is then cast, and then by the foot on the other end, No. 2, of the cross treadle, until the points of the tubes are returned to their former position; then remove the knot by disengaging the hooks and the tubes; then the knots are made tight as the wrought part of the net is rolled on the beam O, on one end of which there is a pulley P, with a band that communicates with the pulley on the end of a short roller Q, in which are fixed four cross bits of wood that answer the purpose of treadles for the feet, by which it is drawn tight; R is another short roller communicating with the roller A, serving to give out the proper quantity of twine for the length of the meshes, or to hold it while the other roller tightens the knot; S is the seat. Fig. 6 is a plan of the machine, the movable bar and treadles left out to prevent confusion. Fig. 7 is the situation of the running knot when the pirn goes through it.

Fig. 9 is the tube in the same position, showing the manner the knot is twisted round it, and having the pirn and slider L taken out of the bar I, the dotted lines showing at what height they come together; in the slider L there are two pins, T, T, to prevent its rising high enough to touch the string, and in the bar I there are two wires O, O, like staples, to support the slider L in its place. Fig. 10 is the movable bar M with the hook. Fig. 11 shows the hooks at large. Fig. 12 is the bar I, showing the notches in which the strings lay to let the pirns pass over them, (when the tubes are brought over as in fig. 7.) Fig. 13 is the slider L, with the pins that move the pirns.—*Trans. Soc. Arts*, vol. xxiv.

Tambour work.

(1051.) *Tambour work by machinery*.—Although this Tambour work can hardly be considered as forming a great branch of British manufacture, yet the number of hands formerly employed upon it was much more considerable than one would have been led to suppose. It is estimated that, before the invention of the tambouring machine, as many as twenty thousand girls and women were employed on this work in the vicinity of Glasgow only, gaining, however, but a very scanty and precarious livelihood. This part of the subject, viz., the actual needlework by hand, it is not our intention to touch upon in this place; it is sufficient to say that, by passing the needle backwards and forwards in particular directions, flowers, birds, and other ornamental work were produced. We propose only to describe the manner in which this is now performed by machinery. The invention of the tambouring machine is due to Mr. J. Duncan, of Glasgow, who has given an interesting

Manufactures.

description of the machines, and the way in which he was led to undertake its construction, under the term of chainwork, in Brewster's *Encyclopædia*, which we propose to avail ourselves of in the present article.

Mr. Duncan states that the first idea of this machine arose from a casual conversation with a gentleman, at that period extensively engaged in the muslin manufacture, and fond of mechanical pursuits. Some study convinced the inventor that the construction of a machine which, by bringing into action a great number of needles at the same time, would shorten the process by manual labour, and might be rendered actually efficient, was perfectly practicable. The diversification of pattern seemed to constitute the whole difficulty, and the application of the composition of forces, acting at right angles to each other, presented a facility of overcoming this obstacle, which encouraged him to proceed. To apply this principle in the various ways which might effect this purpose, did not occur for a long time afterwards, and his first idea was confined to the construction of a machine which might be put in motion by a person who should exercise his discretion in shaping the pattern, whilst he should be enabled to perform all the other operations by the pressure of his feet. It seems more easy to move the cloth than the needles, and for this reason the cloth frame was made to move in both directions; at the same time he received a suggestion that a perpendicular position might admit of many conveniences of which a horizontal one could not be made susceptible, and adopted it. After some consideration, a machine was constructed under his direction, and afterwards a second, which he only occasionally superintended, being at that time engaged in other pursuits. After two years, he formed a connection by which his whole study and time were to be devoted to the completion and practical application of his invention. Six of the machines were set to work in this way; after which he was sent to London by the Company, in order to procure the Patent, and comply with the necessary proviso, which requires a specification of the invention to be enrolled in the Court of Chancery within thirty days of the sealing of the Patent. At this period, the idea of rendering the machine automatic had barely presented itself to him, and, consequently, the last part of the specification only described the possibility of applying such mechanical power. Upon his return, he extended and applied this principle so long as the work was under his direction. The results of that experience, and what afterwards occurred to him, are found in the description which follows.

Pl. lxxiv.
Fig. 1.

Plate lxxiv. fig. 1, is a transverse elevation, viewed in front, or at that part where the person who has the care and superintendence of it is supposed to be placed. At A, A, A, are three upright posts, being exactly one half of what are used, those behind corresponding in every respect with those in front. At B is a horizontal cross rail, of which one is before and two behind. The frame in which the cloth is stretched appears at C, the lower beam and under part being concealed by the beam D, but correspond in every particular with the upper part, which is visible. C is the middle frame, which in that work contains fifty-four needles, each being placed at the distance of one inch asunder, and designed to tambour a piece of muslin six-fourths wide, one whole row being wrought at the same time. The cloth frame is suspended so that it will move freely, and without the exertion of much power, either upwards

or downwards, and with equal facility from right to left, and *vice versa*. To ensure this, the roller G is placed above; and in order that both sides of the cloth frame may rise and sink equally, cords are attached to each end, which, after passing a sufficient number of times round the roller G, descend upon the opposite side, where the weight of the frame is nearly, but not quite, counterpoised by the weights L, L.

The tension of the cloth is preserved by ratchet wheels and catches to either roller, precisely as in a common tambouring tent; and in order that it may be stretched *laterally* as well as *vertically*, at each side is a piece of iron filled with wire hooks which take hold of the selvage of the cloth, as used at bleach-fields, and called by the name of tenters. In the doubling framing at the right hand, that part of the machinery which forms the pattern is contained, and this consists of four wheels fixed upon the same axis, which is a bar of iron one inch square. Of these wheels, three are eighteen inches in diameter, and one twenty-six inches. The wheel nearest to the front of the machine is a ratchet, and merely regulates the motion of the others. It is customary to form two flowers by one revolution of the axis, because when the flowers are similar every second row is reversed, and when dissimilar, every alternate row is of the same form. In the first case, the ratchet wheel forms a flower by half a revolution; in the second, the number of teeth correspond to the number of loops or stitches in the respective flowers; the next wheel in order is to communicate the horizontal motion to the frame in which the cloth is suspended; the third wheel gives the perpendicular motion; and the fourth, or twenty-sixth inch wheel gives a rotary motion to the needles upon their whole axis. The second and third wheels, of course, are those immediately employed in the formation of patterns; and it may be proper in this place to give some account of the principle by which they are fitted for this purpose, as it is by far the most curious and least understood part.

To apply this principle to the construction of the tambour machine, or to any other requiring extensive varied motion, it was only necessary to produce two direct motions, which, as being the most simple and efficient mode of construction, were placed at right angles to each other, one being in a vertical and the other in a horizontal direction; and as it is easier to communicate motion to one body than to many, it was found better that the motions which produce a relative change of position between the cloth and needles, so as to regulate the successive points of perforation, should be given to the former rather than to the latter. In the first construction of the machine, the motion given the cloth frame was effected by two screws, one placed vertically and the other horizontally. As the machine in this state was wrought by the operator's hands and feet, and entirely under the guidance of his discretion, the screws were turned by his hands by two small winches, so calculated that, when either winch was turned to the extent of a quarter of a quadrant of one revolution, a shift of the cloth equal to one-thirty-second part of an inch was produced. This was found a proper length when the motion was directly given by one screw, either vertically or horizontally. But when any immediate angle was to be formed, it required that the shift should be less in both screws, as the oblique line produced by the combining action of both screws was always greater than either side apart, in the same ratio that the hypo-

Mechanical Processes.

Manufac-
tures.

then use of a right-angled triangle exceeds that of either of the sides. When the screws were judiciously turned, this operation succeeded very well; but as the ratio of the one to the other constantly varied, even the most careful operators, totally ignorant of the simplest elementary principles of trigonometry, were in constant danger of errors; and when intrusted to women or boys, which consideration of economy rendered peculiarly desirable, it was found impossible to place much reliance upon the quality and regularity of the work. These reasons, therefore, induced the inventor seriously to endeavour to find some remedy, which, by fixing the motions of the machine under regular mechanical laws, should entirely remove both the blunders and inaccuracies of human agency; and this he was enabled to effect by removing the screws and substituting the traverse wheels. When this point was gained, very little more was necessary to render the machine entirely automatic, and this was speedily effected.

The cloth frame being loosely suspended, and its motion regulated by the cylinder above, it was further suspended by the centre from one end of the lever H, the other end of which was connected, by means of two stout iron wires, with a piece of iron furnished with a small friction wheel, and acting on the rim of the perpendicular traverse wheel directly under its centre. The tendency of the frame to descend produced a gentle pressure of the friction wheel against the rim of the traverse, and according to its shape the frame was either lowered or raised at every shift of the wheel.

The communication between the cloth frame and the horizontal traverse was effected merely by a small connecting bar of iron between the edge of the cloth frame and the wheel, the rod being placed directly level with the centre of the wheel. The pressure against the wheel was very simply effected merely by tying a piece of whipcord to the frame, and, after passing it over a pulley, suspending by it a small weight to its other extremity. A screw was also attached to the breast beam, by which the cloth frame could be raised at pleasure, to present fresh cloth by shifting a notch in the suspensory rod C. Thus ten or twelve rows could be wrought without shifting the beams upon which the cloth was stretched. The general motion was communicated by a leather belt passing over the pulley at N, and the machine could be engaged or disengaged at pleasure, by means very similar to those used for other machinery. When a flower was finished, the ratchet wheel moved a small lever, which instantly stopped the machine in order to prevent accidents. There were three treadles below, moved by wipers upon the cross shaft, by which all the motions were given. The first plate served to set forward the needle frame, so as to produce the perforation of the cloth by the needles; the second, P, set in motion that part of the machinery which supplies the needles with thread, and the third, P, moved the ratchet wheel one tooth between every perforation.

Rope-making.

Common
process
of rope-
making.

(1052.) Rope-making is an Art of unknown origin, and is, with great probability, supposed to be of very ancient date. The fibres commonly employed for the purpose are hemp or flax, but attempts have been made to employ wool and some other materials. The first part of the process of rope-making is that of spinning the yarn or threads, which was formerly, and is at

present, frequently done by men having a quantity of hemp or tow fixed about their waist, and walking backward in long rope-grounds, the thread being twisted by an attendant, or by some first mover at the end of the ground or walk. The sliver of hemp being placed round the waist so that the two ends come in front, the workman draws out a proper number of fibres with his hand, twists them with his fingers, and fixes this twisted part to a hook of a whirl which is driven by a wheel, put in motion as above described; he then walks backwards, supplying the hemp as required, hanging it as he proceeds on hooks fixed for the purpose. As soon as he reaches the end of the walk, another spinner takes the yarn off the whirl and gives it to another person to put on a reel, and then, attaching his own hemp to the whirl, walks in like manner down the ground.

Mechanical
Processes.

The next part of the process is that of stretching the yarns, so as to make them all of the same length, which is called warping; the next is that of tarring the yarn; and the last is that of laying the cordage.

In this, two or more yarns are attached at one end to a hook; this is then turned the contrary way from the twist of the yarn, and thus is formed what is called a strand. Three strands, and sometimes four, besides a central one, are then stretched at length, and attached at one end to contiguous but separate hooks, and at the other to one single hook; and the process of their conjoint combination, which is performed by turning the single hook the contrary way to the other three, consists in regulating, by duly retarding it, the progress of the twist of the strands round their common axis, whilst at the same time the strands receive separately, at their opposite ends, just as much twist as is taken out of them by their twisting the contrary way in the process of combination.

This, in all probability, was the extent to which rope-making arrived for many Ages; as the cordage for ships, and other applications of rope, did not formerly require that size which rendered further combination necessary. The individual yarns composing a strand are limited in their thickness; because, if exceeding a given size, the fibres of hemp or other component substance have not a sufficient number of turns round their common axis to prevent their slipping when the yarn is stretched; therefore, when the rope became thick, the requisite number of yarns to form a strand was very great, and, in general, many were broken on their being twisted together in one spiral; for the outward coat of threads or yarns are necessarily exposed to more stress than the internal ones, lying at less distances from the centre of the cylinder, so that when twisted together, the outside yarns form a spiral of a number of turns round the mass of the included yarns, and are therefore much shortened; whilst the inner yarns take only the same number of turns round a reduced axis, and, from that cause, are less shortened; therefore, it follows, that the outside yarns only can be in full tension, whilst those within must be more or less coiled up according to their proximity to the centre. The result of this erroneous principle of forming strands was obvious, and probably led to the formation of great ropes, by the combination of the lesser ones round a common axis, in the same manner as a shroud-laid rope is formed by the combination of strands round their common axis; and the rope, thus formed by the combination of three shroud-laid ropes, is said to be cable-laid; as, upon this principle, cables and water

Manufac-
tures.

ropes are made, even when their magnitude does not require their strands to be inconveniently large; the object being to make the rope more hard and compact, and thus to prevent the too easy admission of water, which is of course injurious.

The short duration of ropes, exposed to be alternately wet and dry, necessarily led to the invention of some simple and cheap preservative, which, by the general practice of all nations, has been supposed to be best effected by the use of boiling tar, through which a mass of yarns, generally consisting of two to three hundred, are slowly drawn and compressed on leaving the kettle, so as to discharge the superfluous quantity.

In this state, the Art of rope-making continued to near the close of the last century, and, with a few exceptions, is still the same, notwithstanding many very ingenious machines and contrivances, which are, however, but partially employed. Mr. Chapman, in an ingenious Work on this subject, has given these in considerable detail, and we are indebted to him for the following particulars.

Rope-
making by
machinery,
Mr. Sylves-
ter's me-
thod.

(1053.) The first attempt at an improvement was made by Mr. Sylvester, who deposited a model of his machine in the repository of the Society of Arts in the Adelphi, prior to the year 1783.

The design of this machine was to supersede the necessity of a rope-ground, by enabling the process to be carried on in a house; for this purpose he spun the thread on a bobbin and spindle; and by his model, the yarns requisite to make the strands were wound on three separate reels, fixed on frames which turned individually round their axes, and also round a common centre, by which they were all three twisted together into a rope, which was to be wound up or coiled away progressively as made. The great defect of this machine was, that the process of making the strands and twisting them into a rope did not proceed at the same time; but a portion of the strands was first made, and afterwards twisted into a rope, imitating the process in a rope-ground, where the strands and rope are made in separate operations at full length.

The next invention was secured under his Majesty's Letters Patent, in 1784, to Mr. Benjamin Seymour, for a new method of making ropes. This appears to have consisted in substituting horses in the place of men to move the machinery at the head of a ropery, viz., the twisting of the strands, and all the different processes until completed in a cable.

Cart-
wright's
Patent.

In 1792, the Reverend Edmund Cartwright obtained a Patent for a machine for making ropes, which he called a cordelier.

This machine was so far similar to Mr. Sylvester's, that three separate reels, containing the yarns to compose the strands, were placed on as many frames, each turning round its individual axis, whilst the whole moved round an axis common to the three; but it differed essentially from the former, by both these motions proceeding at the same time; so that the twisting of the strands and of the rope kept pace with each other, and were therefore capable of producing the desired end, the rope being progressively drawn away as made.

Fothergill's
Patent.

In 1793, Mr. Richard Fothergill, of Sunderland, in the County of Durham, obtained a Patent for "a machine for dressing hemp, and making and spinning the same into ropes and cordage." This invention consisted in a method of heckling and preparing the hemp, and in spinning it into rope yarn; and in laying the cordage by

a machine on the principle of Mr. Cartwright's, but differing from it in its being vertical like Sylvester's, whilst the revolving shafts of Mr. Cartwright's were horizontal, and more particularly in its internal regulations. It was capable of making ropes without the necessity of a rope-ground; but, excepting so far as any advantage arose from the greater uniformity of the whole process, it went only to the reduction of labour, and concentration of it to a more limited space. It was, however, carried into effect upon a large scale, and at a great expense in buildings and machinery, at Southwick, on the river Wear; but was at first very limited as to the manufacture, until such further improvements were adopted as will be subsequently described. A perspective view of that part of this machinery for making ropes is given in plate lxxviii., fig. 1, in which *a* is the platform, by the revolution of which the three strands are twisted into ropes at *b*, their point of junction, from which it is drawn forward as made by the wheel *d*; *c, c, c* are the separate strand wheels, each containing the requisite number and length of yarns for a strand, and fixed in its respective strand frame, revolving round its own axis at the same time that they are all carried round by their supporting frame *a*. Fig. 2 is a yarn spindle and bobbin.

Mechanical
Processes.

Pl. lxxviii.
Fig. 1, 2.

(1054.) In the same year, i. e. 1793, Mr. John Daniel Balfour, of Elsinour, in the Kingdom of Denmark, obtained an English Patent for his "new invented machine for making and manufacturing ropes and cordage." We have already described the usual process of forming the strand of a rope, and shown that it must be defective; because a given number of spirals round a large cylinder must require a greater length of yarn than the same number of spirals round a small cylinder of the same length as the large one.

Balfour's
Patent.

To remedy this, Mr. Balfour's method was to stretch out at length in a rope-ground all the yarns wanted for the formation of a strand, to such length as the strand was required to be; the residue, viz., so much at least as the length of the yarns would exceed the proposed length of the strand, was to be wound up on as many individual bobbins upon a large frame as there were yarns. Those yarns were separated at intervals, throughout the whole length from the frame to their commencement, where the operation of twisting the strand was to begin. Here the yarns were all united, either through concentric circles of holes, or round the notches of an implement which he called a *top minor*. The operation then began by twisting the whole of the yarns in mass at that end, and retiring with the top minor as the twist advanced. In this case, as the yarns at the opposite end had the means of drawing off individually from their separate bobbins, they each would unwind no more than their internal or external position in the spiral required, and would, of course, be of different lengths. This plan was very ingenious, and had much merit in its principle, although defective in stopping short of what would effect the ultimate purpose of causing all the yarns to bear alike on breaking the rope. Before a rope is brought to its breaking stress, both it and the strands composing it are much elongated, and their diameters greatly reduced. Now, under any reduction of diameter of strand, it is apparent that the outside coat of yarns must slacken considerably, and give little or no support to the internal yarns, which, from the smallness of their spiral, could elongate but little, and must, of course, break in succession from the centre outwards. In addition to this defective circumstance, the mode

Manufac-
tures.

Huddart's
Patent.

of operation was so complex and laborious as to prevent its adoption.

The deficiency, in point of principle, in the above method, was remedied in a Patent taken out also 1793, by Mr. Joseph Huddart, of Islington, in the County of Middlesex, for "a new mode or art of making great cables and other cordage, so as to attain a greater degree of strength therein, by a more equal distribution of strain upon the yarns."

Mr. Huddart's formation of the strand is essentially the same process, except that he places, behind the movable implement which Mr. Balfour calls a top minor, a tube of two parts divided longitudinally, and overlapping each other, which is formed of thin steel, of spring temper, to be more or less compressed at pleasure.

The top minor of Balfour is with Mr. Huddart composed of a plate with the requisite number of holes for the yarn, placed in concentric circles; and connected with this plate, at such a distance as to admit the easy concentration of the yarns, is the tube just spoken of, which is united to a graduated instrument, called by Mr. Huddart a register, on which there is an index to denote the proper angle of twist during the process, and which is also used to regulate the increased angle of the next process. The yarn reels were placed individually in a stationary frame at the head of the rope-ground; and it appears that the register was to be conveyed onwards towards the yarn frame, as the strand was twisted by the hook of a sledge, at the end where the process commenced, until the whole strand was made.

This part of the process is similar to Balfour's, which Mr. Huddart perfected by giving to the mass of yarns, thus formed into a strand, an additional twist, by which the strand was shortened, and provision made for the effects described to be produced by the reduction of its diameter on being stretched.

In point of principle the plan described by Mr. Huddart was complete, but his mode of carrying that principle into effect was so far complex and laborious, that, excepting the making a few ropes by way of trial, and which proved far superior to the common manufacture, the invention laid dormant and was relinquished. Mr. Huddart's specification also included a method of twisting the yarns, during the process of their being formed into a strand, as a preventive to their loss of strength by untwisting so much as the countertwist of the strand would otherwise occasion. (See *Repertory of Arts*, vol. iv. Second Series.)

Chapman's
Patent.

In 1797, Mr. William Chapman, of Newcastle, obtained a Patent for "laying, twisting, or making ropes or cordage of any number of yarns or strands, or any number of threads tarred or untarred, from the size of a cable down to the smallest line, composed of more than one thread." This invention was principally to reduce the charge of labour, and to render rope-grounds unnecessary. The strands revolved round their own axes only, and the rope was formed by the revolution of a distinct axis or frame on which it was coiled; it was capable of making, on the common principle, shrouded ropes and cables of any size, and dispensing with the use of a rope-ground. The essential difference between this invention and those described above is, that the parts of the machine which twist the strands are less cumbrous and complicated than by the planetary revolution of the strand frames; but whatever is gained by

their being stationary, is lost on the other hand by the necessity of giving a rotary motion to the rope, and the greater difficulty of coiling it away; more particularly in large cordage, in which the advantage lies with the planetary method.

Mechanical
Processes.

In the following year, Mr. Chapman obtained another Patent for "laying, twisting, or making ropes and strands of ropes, and of coiling up such ropes and strands of ropes during the process of making." The invention consisted first in tarring the yarns in such a manner as to cause them all to wind up singly, as they should come from the tar-kettle; which facilitated the process of manufacturing rope in any way and gave all the yarns a full bearing in the strand. Secondly, it consisted in making the strand separately in two distinct ways by house machinery, viz., either by having the yarns on separate reels fixed on a platform, supported on or in the revolving shaft or frame, by which, after the yarns were concentrated to a focal point, the strand was to be twisted, and from thence progressively drawn forward, and wound up as made by machinery in a stationary position; or by fixing the reels in stationary frames, and conducting the yarns separately to one general focus, over or opposite to a revolving shaft or frame, in which the strand has to be wound up as made, and which, as a most essential part of the invention, contained the machinery which was to haul forward the yarns composing the strand. These two (and a combination of them) included all the possible methods by which a strand could be made, without a rope-ground, so as to give each yarn a different length in the strand according to its distance from the centre.

Second Pa-
tent by Mr.
Chapman.

Something like the latter had been used to wind up, with a small twist, a number of yarns preparatory to their being made into a strand; but its hauling forward machinery consisted in two rollers on a stationary and separate frame, close to the opening in the top of the axis of the revolving shaft, which twisted the yarns prepared for a strand, and contained the reel on which it was wound up. The two rollers which compressed and brought forward the yarns necessarily drew them out of the same length, and prevented the yarns being twisted into a mass in any other way than on the old defective principle.

On obtaining this Patent, a machine that received its motion from a crank, and which was erected in a warehouse in Newcastle, for making ropes of five inches girt and under, was tried, and a few ropes for experiment, and some large strands, were made; which latter, on being broken by suspended weights, gave a very favourable result; and the inventor, subsequently simplifying his apparatus, Messrs. Hood and Co., of Newcastle, adopted the machinery, and the same was afterwards adopted in the King's yards.

Mr. Balfour obtained a second Patent, in 1798, for "improvements in the operation or working part of a machine formerly invented by him for making and manufacturing ropes and cordage;" which contained nothing more than the last-described method, except mentioning circumstantially his manner of turning the strand hooks, and of heaving the sledge backwards, which was also by a capstan; and like the one to which it is compared, as not differing, it leaves the backward motion of the sledge and the twisting of the strands to be regulated by the eye of the workmen; which, of course, must be defective, from having so uncertain a criterion. Mr. Balfour had previously tried in the King's yards his

Balfour's
second Pa-
tent.

Manufac-
tures.

Chapman's
third Pa-
tent,

first method, and that failing of the desired success, he effected the latter, for which he received a considerable reward from the Navy Board.

Mr. Chapman, seeing the imperfection of this first invention of the backward motion of the sledge, which is the most simple method of forming strands on a perfect principle, conceived the idea of so regulating the motion of the sledge backwards, that it must at all times travel neither more nor less than the speed predetermined; so that for every revolution of a strand, the sledge should retire precisely the length of the axis assigned to it, and of course occasion the twist to be uniformly regular; the close approximation to which is an object of importance in the acquisition of strength.

For this he again took out a Patent in the same year. The first object, that of uniformity of twist, he attained in the following manner, *viz.*, by stretching a rope, which, he called a ground rope, the whole length upon the floor of the ropery. This was passed, in the form of the letter S, partially round two or more grooved wheels with horizontal axes, fixed with other apparatus on the common machine for making ropes, technically called a sledge; but which, for this purpose, is fitted with wheels to travel on a rail-road. The grooved wheels press against each other to bind the rope, and have upon their axes tooth wheels connecting them with each other, and finally with the hooks for turning the strands; which, in this instance, are all turned by one great crank intervening between the hooks, and the wheels appropriated to the backward motion and connected with the ground rope. Thus, when the hooks were turned by the crank, the sledge was also drawn backwards by the turning of the grooved wheels, which received any determinate motion to that of the strand hooks by means of changeable wheels easily taken off and on.

In the preceding instance, the labour of the men is relieved by a rope leading from the sledge to a horse capstan, at the foot of the ropery. In consequence of the ground rope (which is capable either of drawing the sledge forward, or retarding its motion) the horse cannot draw the sledge faster than it ought to move; but his spare power is given in aid of twisting the strands through the intervention of the wheels, which connect that operation with the backward motion.

Machinery
described.
Pl. lxxviii.
Fig. 3, 4,
5, &c.

(1055.) The principal parts of this machinery are represented in plate lxxviii. fig. 3, 4, 5, &c.

Fig. 3 and 4 show the methods of stopping the twist of the hemp.

Fig. 5 the gripping sheaves to hold a rope from slipping, and which (but in a greater number) are used on the sledge in fig. 6, which is a side elevation of the tackle board at the head of the ropery, and of the sledge departing from it to haul out and twist the strands. In this figure, *a* is the tackle board, with a yarn guide and press blocks upon it, and with the lever to weight the blocks according to the magnitude of the strand. The upper half of the block rises or falls (perceptible only by the lever of the weight) with every incidental variation of the thickness of the strand, so that the resistance is always uniform, notwithstanding the interposition of two or three thick parts of yarns. *c c* the ground rope by which the sledge *b* is hove out by the motion of the wheels over which the ground rope passes, and which motion keeps its due pace with the turning of the strand hooks. *d* is a small windlass to tighten the ground rope, the other end of which is made fast at the foot of the rope-ground.

Fig. 7 is a plan of the tackle board and sledge, with part of their apparatus. Mechanical Processes.

Fig. 9 a plan of the lower half of the press block.

Fig. 8 an elevation of the upper and lower part of the press block.

Fig. 11 the yarn guide, or perforated plate, through which the rope yarns pass individually to concentrate at the press block.

Fig. 10 one of the strand frames for making a rope on the new principle at one operation.

A shows the upper division of the frame, with its reels, yarn guide, press blocks, and lever and weight, to make a primary strand after Mr. Balfour's principle, which, with the other two upper divisions, receives its motion from the wheel *i*.

B is the lower division of the frame, with its sheaves, round which the strand passes to compel it to receive the additional twist put into it by the wheel *h*, which is on the same axis with *i*. *g* is a loose wheel on the same axis with *h* and *i*, and which receives its motion from the wheels *e* and *f*, which are connected together, and move freely on the axis of the lower division B, and receive motion from a bevel wheel on the lower sheaves, round which the strand passes; and the rope (or three strands combined under the extremity of a fixed top) is drawn away by the machinery of the rope frame in which the rope is wound up as made. The use of the described machinery is to compel all the three strands to come forward with an equable motion, without which one strand would appear higher than another in the rope. A is a platform on which a coil of shroud-laid rope may be placed for the purpose of making a cable, in which case the yarn guide is taken away, and both divisions of the frame perform the same revolutions. The end of the rope is passed through the centre of the coil, and of the axis of the frames, which are hollow.

Fig. 12 and 13 show a spindle calculated to spin and take away a rope yarn, with any determinate number of turns, from women or children in a stationary position.

Mr. Chapman having, by his last Patent, invented an accurate method of proportioning the backward motion of the sledge to any predetermined twist of strand, conceived that it would be a great improvement to apply the power of a steam-engine to such locomotive machinery as is necessary in rope-grounds; and having discovered an easy method, he, conjointly with Mr. E. W. Chapman, on July 26, 1799, took out a Patent for it and other inventions, under the title of "A method or methods of making cords and ropes and cordage, both tarred and untarred, from the spinning of the yarn inclusive, to the finishing of the rope or cordage." This new method consisted of many parts. The first was an improvement in spinning the yarn, which, in the usual mode of spinning with the hemp round the waist, has all the imperfection of the mode of forming strands according to Mr. Balfour's method; each fibre of hemp being drawn out of different lengths into the yarn, accordingly as its distance from the centre required, similarly to that of the respective yarns forming a strand by the method mentioned, which is immediately apparent on untwisting a piece of yarn as the outward fibres will become slack; therefore, as the yarns composing a strand are necessarily untwisted by the countertwist of the strand when laid, it followed that the remedy of this imperfection was a desideratum.

Mr. Huddart, in his Patent of 1793, had, as already related, retained the strength of the yarns by giving

Manufac-
tures.

Another
Patent by
Mr. Hud-
dart.

each separate yarn a countertwist to the strand during the operation of its being made. This method was capable of producing the effect intended, but was too complicated, and required too much room to be carried into effect on an extensive scale.

The method now invented was to effect the end, in the act of spinning, which was done by women and children in a stationary position, one to each spindle and bobbin. The double twist was made by dividing the spindle, and giving it two separate motions, or it was done by a second process. Superior strength was thus obtained, as will appear by the following experiments made before Mr. Watson Fenwick, master rope-maker to his Majesty's yards at Chatham.

Experi-
ments.

(1056.) *Experiments.*—On April 29, 1801, Mr. Fenwick spun a thread of yarn, at Willington ropery, of the usual size, from the common wheel, and another on the double spindles; on the first spindle putting in ten turns per foot, as drawn from about his waist, and on the second spindle six additional turns. A piece of each was then broken in the state in which it was spun; the strength is shown in column No. 1. Another piece of each was then broken, after taking out two turns per foot, the strength of which appears in column No. 2.

	No. 1.	No. 2.
Common spun . . .	135 pounds	100 pounds.
Machine spun . . .	205 „	220 „

The deduction is obvious, the machine-spun yarn of the two twists being not only the strongest in its original state, but it gained strength by twists being taken out of it, as must be done in making them into a strand, whilst the other, by the same process, lost strength.

On the mean of four pieces of machine yarn, of the usual size of eighteen threads to the strand of a three-inch rope, which were tried subsequently to the preceding,

	Pounds.
The yarn, with the twist it had from the machine, broke with	194
The same yarn, with three turns per foot taken out	235
Hand-spun yarn of the same size, and spun from the same parcel of hemp, which was remarkably good, bore as under:	
As spun	175
With three turns per foot taken out	128

This process, however, incurring an extra expense, was never practised; but some portion of the effect of the double twist may be obtained in the common process of spinning, by giving the whirls whilst the spinners go backwards as slow a turn as the men can admit of without the threads breaking, and causing them, when the threads are spun to their full length, to continue until the additional twist be put in, or leaving a boy for that purpose to attend every four threads, (the number usually wound up together,) and then to follow them in.

It has already been stated that strands, made on the new principle, compared with those after the old method, possess individually as strands a superiority of strength of upwards of three to one, when each contained 144 threads; but, when made into ropes, that disparity is reduced to considerably less than two to one.

It also follows that in yarns this individual superiority is reduced when made into strands.

Hand-spun yarns are rarely spun uniformly, and, when broken individually, necessarily give way in their

VOL. VIII.

weakest parts, though only a small portion of their length, but, when combined in a strand, they then exert the average strength of all their parts, so that, on experiment, a well-made strand has been found to bear more than the sum of the individual strength of pieces of two feet length of the same yarns, although, theoretically, the strand should be considerably weaker.

The most easily available parts of the improvements stated in the specification of this Patent were,

1. The application of an endless rope (moved with considerable speed, and reaching from end to end of the rope-ground) to machinery in any part whether stationary, or changing position as ropers' sledges necessarily must. This was effected by passing the bight of the endless rope round suitable grooved wheels on the sledges, and thus giving motion to the machinery.

2. Correspondent machinery at the head of the ropery, to the axes of which the ends of the strands were attached during the making of the rope, was so contrived that the axes possessed the capability of varying their respective revolutions, during the act of moving, so as to admit of any of the strands being tempered and brought to a fair bearing.

By these means all ropes, from a small size to the largest, are capable of being made, either upon the old or new principle, without the aid of more men than necessary to attend the machinery, and take out and put in the stake heads, as the top (or implement round which the strands twist themselves into a rope) progressively moves up the rope-ground, which, like the rest of the movable machinery, it does upon a railway.

The advantage of this process is apparent, first, as each respective motion and comparative revolution of strand and rope is predetermined and fixed by changes of wheels, every part of the work is conducted in a uniform manner and not liable to mistake, as tables are made out, stating what wheels are to be used; and, secondly, in place of 200 men, which are usually employed in closing a twenty-one inch cable, fourteen are only required, and they can also coil it away with the help of the steam-engine, which is only of eight-horse power.

(1057.) *Manufacture of flat ropes.*—In many cases a flat rope is very desirable, as in drawing up coals, &c., from mines, and several propositions have been made and Patents taken out for the formation of them. The first of importance was by Mr. John Curr, of Sheffield, for a method of forming and making a flat rope, intended to be used in drawing coals and other minerals and water out of mines of any kind. His specification says, "The said flat ropes may be formed by connecting two or more small ropes sideways together, by sewing or stitching, lapping, or interlacing with thread or small ropes, &c."—He then describes his machine for stitching them together.

It was found necessary to make the constituent ropes alternately of a right-hand and left-hand twist, to keep the flat rope in a quiescent state; and in this form, composed of four small shroud-laid ropes, these were used for some years, in the Midland Counties, for drawing coals: these ropes wind up in a spiral on themselves.

In 1807, Mr. William Chapman and Mr. Edward Walton Chapman, of Newcastle-upon-Tyne, obtained a Patent for "a method or methods of making a belt, or flat band, for the purpose of drawing coals or other minerals up the pits or shafts of mines, and for raising of heavy articles in any situation whatever."

Mechanical
Processes.

Manufac-
tures.

This invention consists in the combination of two or any greater number of strands of shroud-laid rope (*viz.* of primary strands composed of yarns twisted together) placed side by side, so as to form any determinate breadth of belt or flat band, and, in a locomotive machine, for stitching or rivetting them together whilst stretched at full length.

The primary strands composing the belt should, in general, be alternately twisted the contrary way to each other, and the yarns should be twisted the contrary way to the strands they compose. The peculiar advantages to be derived from these flat belts arise from the following circumstances, *viz.*, "that the loss of strength, by the combination of these strands into a shroud-laid rope, is so considerable, that, exclusive of the reduction of length from being twisted into a rope, which is usually about one-sixth, the strength of two strands, made in such a way as to make all the yarns bear an equal tension, or nearly so, will, when laid side by side, be nearly equal to that of three such strands combined as a rope; from which result the chief advantage in forming the strands into belts, instead of making them into ropes." Finally, "all that this invention consists of is, the use of strands laid side by side, so as to acquire a strength which ropes used in this manner would not have." And also in the invention of "the truck or frame, with its apparatus for combining speedily and correctly together any requisite number of strands or other flexible substances laid side by side."

In the preceding extract from the specification, it appears that the invention rests on two points: one of which is, that the machine for uniting the strands together is locomotive, by which means strands, or other flexible substances, may be united together, whilst stretched at length under an equable stress, so as to take away their liability to disunion, from the breaking of the stitches or other fastenings, on receiving sudden jerks. The other result of this invention is, that by it belts are formed on that principle which gives their immediately constituent parts the greatest possible strength attainable from rope yarns; because a primary strand, made after the perfect manner described in the preceding columns, is of greater strength than would be produced by the same yarns extended straight by each other, and bound at intervals into a cylindric mass, called by seamen a salvagee; although Duhamel and other writers have supposed the latter to be the strongest combination of yarns, which it certainly was in large combinations before the recent improvements. At present it is not so, because rope yarns are rarely if ever of uniform strength for any great length; and therefore, when acting individually, as in a salvagee, each yarn must break in the weakest part: whereas, in a strand on the preceding principle, the small portion of strength that is lost by the oblique direction of the outside shells of yarn, is much more than counterbalanced by the yarns binding each other, so as to prevent slipping; and consequently, by their acting with a force equal to the mean strength of each yarn, which, as the extent of the weak parts is in general but a small proportion of their whole length, will conjointly give a force considerably beyond the sum of the resistances of the weakest parts of each yarn. Finally, the utility of this invention chiefly rests on the superior strength derived from the novel combination of certain constituent parts of a well known whole, which is perfect in itself, *viz.*,

a shroud-laid rope, but whose constituent parts are imperfect, and cannot be brought into use singly, because, without some further combination, they would untwist and become useless. The decrease of strength, arising from three primary strands being twisted together into a hawser or shroud-laid rope, is much beyond what it ought to be theoretically. The reduction of strength should be similar to the decrease of length, which commonly is one-sixth or less, and it is difficult to account satisfactorily for the excess of deterioration: but the same defect takes place in the combination of three hawsers, or shroud-laid ropes, when they are formed into a cable. This has been satisfactorily proved by breaking many cables, from six to eight inches girt, and their strands separately, at Willington ropery. The ropes were made on the principle of causing the yarns to bear equally; and the result of many trials was, that one of the cablets bore five per cent. more than twice the strength of one of its strands, and, in the other instances, they generally were from five to ten per cent. deficient of twice the strength of one strand; from which is proved the impolicy of continuing the old method of making the lower shrouds of large ships cable-laid, and sometimes the top-mast shrouds; because, if made hawser-laid, three-fourths of the weight of rope would be much stronger.

An immense number of Patents, besides those above mentioned, have been taken out, which our limits will not allow us to particularize; in several cases the same person taking out several, as was the case with Mr. Chapman, Captain Huddart, Mr. Belfour, Mr. Curr, and Mr. Grimshaw, of which, however, that of Captain Huddart, for cables, was considered the most scientific: but, as we have already stated, the introduction of the iron cable has so much altered the demand, that in general the machinery for hempen cables is nearly useless. We shall conclude this article by the following Tables, showing various particulars connected with rope-making, strength of ropes of different sizes, &c.

(1058.) TABLE, showing the number of Fathoms and Feet in a Hundred Weight of Rope, of any Size under Fourteen Inches.

Inches in Circumference.	Fathoms in a Cwt.	Inches in Circumference.	Fathoms in a Cwt.	Inches in Circumference.	Fathoms in a Cwt.
	Fa. Ft. In.		Fa. Ft. In.		Fa. Ft. In.
1	486 0 0	5½	16 1 0	10	4 5 0
1¼	313 3 0	5¾	14 4 6	10¼	4 4 1
1½	216 0 0	6	13 3 0	10½	4 2 0
1¾	159 3 0	6¼	12 2 0	10¾	4 1 0
2	124 3 0	6½	11 3 0	11	4 0 0
2¼	96 2 0	6¾	10 4 0	11¼	3 5 0
2½	77 3 0	7	9 5 6	11½	3 4 0
2¾	65 4 0	7¼	9 1 6	11¾	3 3 0
3	54 0 0	7½	8 4 0	12	3 2 0
3¼	45 5 2	7¾	8 3 6	12¼	3 2 0
3½	39 3 0	8	7 3 6	12½	3 2 0
3¾	34 3 9	8¼	7 0 8	12¾	2 7 0
4	30 1 6	8½	6 4 3	13	2 5 0
4¼	26 5 3	8¾	6 2 1	13¼	2 4 0
4½	24 0 0	9	6 0 0	13½	2 4 0
4¾	21 3 0	9¼	5 4 0	13¾	2 3 0
5	19 3 0	9½	5 2 0	14	2 2 0
5¼	17 4 0	9¾	5 0 6		

Mechanical
Processes.

Manufactures.

TABLE, showing the Weight of One Hundred and Twenty Fathoms of any Cable or Rope, for every half Inch of Circumference, from Three to Twenty-four Inches.

Inches in Circumference.	Weight.	Inches in Circumference.	Weight.	Inches in Circumference.	Weight.
	Cwts. qrs.		Cwts. qrs.		Cwts. qrs.
3	2 1	10½	22 2	18	81 0
3½	4 0	11	30 1	18½	85 2
4	4 1	11½	23 0	19	90 1
4½	5 0	12	36 0	19½	95 0
5	5 1	12½	39 0	20	100 0
5½	7 0	13	42 1	20½	105 0
6	9 0	13½	45 7	21	110 0
6½	10 2	14	49 0	21½	115 2
7	10 1	14½	52 2	22	121 0
7½	14 0	15	56 1	22½	126 2
8	16 0	15½	60 0	23	132 1
8½	18 0	16	64 0	23½	138 0
9	20 1	16½	68 0	24	144 0
9½	22 2	17	72 1		
10	25 0	17½	76 1		

TABLE, showing the different Kinds of best Bower Cables at present employed in the British Navy, with the corresponding Iron Cables.

Rates of Ships.	Best Bower Hempen Cables 100 Fathoms.		Number of Threads in each.	Breaking Strain by Experiment.	Diameter and Weight of the Bolt of Iron Cable substituted for the preceding.
	Sizes. Circumference.	Weight.			
	Inches.	Cwt. qrs. lbs.		Tons cwt. qrs.	
First-rate large ..	25	114 3 7	3240	...	
Middle	24	105 2 17	2988	...	
Small	23	96 2 27	2736	...	2½ inches.
Second-rate	23	96 2 27	2736	114 0 0	218 cwt.
Third large	23	96 2 27	2736		
Small	22	89 0 12	2520		2 inches.
Fourth 60 guns ..	21	80 0 22	2268	87 0 0	186 cwt. 2 qrs.
58 ditto.	19	66 0 21	1872	...	1½ inch.
50 ditto.	18½	62 1 14	1764	...	170 cwt. 2 qrs.
Fifth 48 ditto.	18	58 2 6	1656	63 0 0	
46 ditto.					1½ inch.
42 ditto.	17½	56 0 1	1584	...	145 cwt. 3 qrs.
Sixth 28 guns.	14½	38 0 21	1080	40 0 0	1½ inches.
Ship sloop	13½	33 0 10	936	...	87 cwt. 2 qrs.
Brig large	13½	33 0 10	936	...	1½ inch.
Ditto small	11	21 2 15	612	...	74 cwt. 3 qrs.
					1½ inch.
					61 cwt. 1 qr.

TABLE, showing the comparative Strength of Shroud and Cable-laid Ropes of the common Kind, and those of Mr. Chapman's.

SHROUDS.		CABLES.	
Common made.	On Chapman's improved Principle.	Common made.	On Chapman's improved Principle.
Girt. Inches.	Girt. Inches.	Girt. Inches.	Girt. Inches.
3½	3	7	5½
4	3½	8	6½
4½	3¾	9	7½
5	4	10	8½
5½	4½	11	8¾
6	4¾	12	9½
6½	5	13	10½
7	5½	14	10¾
7½	5¾	15	11½
8	6	16	11¾
8½	6½	17	12¾
9	6¾	18	13
9½	6¾	19	13½
10	7	20	14½

Mechanical Processes.

Hat Manufacture.

(1059.) The manufacture of felt hats, which is the only kind we shall describe in this article, is an exceedingly curious process, and is carried to a very considerable extent in this Country, where the use of this sort of covering for the head is more general than in any other nation in Europe; for not only are felt hats the universal covering amongst the upper and middle classes of the English, but the peasant likewise commonly considers such an article of dress as indispensable, although, perhaps, of late years, straw hats have, in some measure, supplanted the felt hat in our country villages. For the following interesting historical sketch of the use of hats, the process of felting generally, and for the process of hat-making both by hand and machinery, we are indebted to Arthur Aikin, Esq., Secretary to the Society for the Encouragement of Arts, &c., being the subject of one of his instructive lectures delivered before the members of that Society.

Early use of hats.—The use of hats, that is, of caps with brims to them, is of very ancient date among the Greeks; the Dorian Tribes, probably as early as the Age of Homer, were characterised by the broad-brimmed hats which they wore when on a journey. The same custom prevailed among the Athenians, as is evident from some of the equestrian figures in the Elgin marbles. The Romans appear in general to have used no covering for the head except a corner of the *toga* or upper garment; but at sacrifices and festivals they wore a bonnet or cap, and this being permitted only to freemen, part of the ceremony of manumitting a slave consisted in putting one of these caps on his head. But on a journey, the Romans were accustomed to wear a hat with a margin wide enough to shade their faces from the sun, called *petasus*.

In the Middle Ages, the bonnet or cap with a narrow margin in front appeared to have been in use among the laity, while Ecclesiastics wore hoods or cowls; but Pope Innocent IV., in the XIIIth Century, allowed to the Cardinals the use of scarlet hats; and about the year 1440, the use of hats by persons on a journey appears to have been introduced into France, and soon became common in that Country, whence probably it spread to the other European States. The cap of the Ancients was certainly made of wool, and this as well as the hat was probably knitwork. When felt was introduced as a material for hats is not known, but it is stated that the hat worn by Charles VII. of France, on occasion of his triumphant entry into Rouen in 1440, was of felt.

(1060.) Concerning the origin of felt little is recorded, and that little is, perhaps, not greatly to be depended upon.

A person, some call him a Monk, having used some carded wool by way of socks, found that the fibres, by long friction between the foot and the shoe, had matted together so as to produce a firm texture like cloth, and from this hint arose the manufacture. Specious as this account or tradition may appear to be, it deserves to be remembered that the Turcomans inhabit tents covered with black or white felt, and that some of the wanderers among the Crusaders may have brought the art of felting from Asia to Europe.

In order to understand the mechanism of felting, and to qualify us to judge of the efficacy of the processes by which it is brought about, it will be necessary to enter

Manufac-
tures.

into some preliminary inquiries respecting the structure of hair and wool; and for these we are chiefly indebted to a short paper by M. Monge, published in the *Annales de Chimie* for 1770.

If we take a common hair of the head, and, holding it fast by the root end, draw it gently between the finger and thumb, it passes through smoothly and with hardly any sensible resistance or interruption; whereas, if we reverse the motion by holding the hair by the point and drawing it from point to root, a very sensible tremulous resistance will be experienced, accompanied by a creaking kind of sound; again, if we place a hair loose between the finger and thumb, and then, by alternately bending and extending them, give them a backward and forward movement, the hair will be put in motion; and this motion will be always from root to point, whether the root be in one or in the opposite position with respect to the two rubbing surfaces. A fibre of wool likewise, in similar circumstances, always moves in one direction. Every schoolboy knows that an ear of a barley-corn, if put within his sleeve at the wrist, soon travels upward to his armpit; and that a single awn of barley, when rubbed in the direction of its length between the finger and thumb, will move only one way, that is, from root to point. The awn of barley is visibly jagged at the edge like a saw, the teeth pointing obliquely upwards, and this particular conformation is manifestly the reason why it is capable of motion in one direction but not in the contrary. A similar structure might be expected in hair and wool, but even the microscope fails to detect any thing very satisfactory in this respect; we frequently, indeed, see, or seem to see, transverse lines, and these may, perhaps, be rings of fine points, or edges of scales; or the structure may be so minute as wholly to elude our sight, although we are quite certain from the effects what the general arrangement of the parts must be; wool in the yolk, that is, with the natural grease of the sheep adhering to it, will not felt, because in this state the asperities of the fibre are filled and smoothed over, just in the same manner as oil diminishes and almost destroys the action of the finest files. But fine wool, that has been properly scoured, has so strong a tendency to mat, or intertwist, or felt, for all these words only imply various degrees of the same thing, that it cannot be spun into an even thread without being previously oiled sufficiently to suspend this tendency. Another example of the facility with which wool felts is, the common flock mattress, which is made of carded wool sewn up in ticking; the warmth and slight motion which it gets by being lain upon are sufficient to cause the fibres to accumulate round certain points, whence result those knobs and lumps of imperfect felt which render it necessary after a time to empty the bag and recard its contents.

A piece of woollen cloth that has undergone no process after that of weaving, may without difficulty be unravelled; but after it has passed through the fulling mill it is no longer subject to this action, the filaments of which each adjacent thread is composed being entangled together by a species of felting. The result of this is, that the cloth shrinks in length and breadth, but becomes proportionally thicker and more dense. The higher the heat is to which the cloth is exposed, and the longer it is continued, the more complete does the felting become; on which account it is that the modern practice of giving a gloss to woollen cloths by rolling them up very tight and then boiling or steaming them for some

hours, gives them a compactness and leathery consistence, in which all the advantages both of felt and of woven cloth appear to be united. Mechanical
Processes.

But the structure of wool and hair, as already described, is not of itself sufficient to account for the formation of felt; on the contrary, it might be expected that the filaments being, when put in motion, free to move only in one direction, should continually diverge more and more from one another. This would actually happen in an attempt to make dense felt of unprepared hairs of any kind, because all hairs are straight, or rather have only one gentle curve from point to root, and likewise possess a considerable degree of stiffness or elasticity. The fibre of wool, on the contrary, is naturally crinkled, or of a zig-zag figure, which it retains with great pertinacity, for, if drawn out till straight, it immediately contracts again to its former figure on being let go. Now this figure, besides opposing a great resistance to the progressive motion of the filament, must have a continual tendency to change the direction of such motion. The result of this would be the formation of a ball, if the pressure were equal on all sides, or a plate or layer, if the chief pressure were only in two opposite directions.

(1061.) We now proceed to describe the Art of hat-making; in which we shall enter so far into its details as sufficiently to give the reader a clear and satisfactory view of the several stages of this very important manufacture. Process of
hat-
making.

Hats are worn in this Country by people in every rank of society, and till within the last thirty or forty years the only essential difference between them was in quality, and consequently in price; the most costly being made of the best materials, and by the best workmen, while the cheaper ones were of inferior materials, and by inferior workmen; of late, however, the increased price of beaver has led to the substitution of silk for the roughing or nap of felt hats; and a diminution of weight has still more recently been obtained by the substitution of silk or hemp as the material of the body of the hat. We may therefore distinguish five kinds of hats: the beaver hat, of which the body is felt and the nap of beaver; the plate hat, with a body of felt and a nap generally of musk rat, neuter, or some other inferior fur; the felt hat, with a body of felt and without any nap; the silk hat, with a body of felt and a nap of silk plush; and, lastly, a hat with a body of hemp or waste silk and a nap of silk plush.

The general mode of making the three first kinds being the same, we shall give as full a description, as our present object requires, of making the finest or beaver hats, after which a few words will suffice to describe the difference between these and the other two kinds. The material of which the body of the hat is formed are lamb's wool, Vigonia wool, and red wool, *i. e.* the woolly hair of a species of camel, a native of the Andes, the different varieties of which are known by the names of lama, vicuna, and pacos, and rabbit's fur. The nap, or, to use the technical word, the *roughing*, consists chiefly of beaver down mixed with the better qualities of neuter hair, and the long down from the back of the English hare. The wools are shorn from the live animal, but the fur or hair is taken from skins, by first drawing out by the roots, by means of a blunt knife, the long and coarse hairs, which are rejected, and afterwards shaving off, with a very sharp knife, the down or finer hair for use. It is by no means a matter of indifference whether the down is drawn out of the skin or shaved

Manufac-
tures.

off, since in the former case the down would have the bulbs or roots attached to it, and thus would with great difficulty make its way among the other materials. Rabbit's fur, although very tender, pliable, and possessed of but little elasticity, will not felt near so readily as wool; and as this is the only fur admitted into the body of the hat, which ought to be made as dense and compact as possible, a part of the rabbit's fur is subjected to the action of moderately diluted nitric acid, or of acid nitrate of mercury. This is done by dipping a brush in the liquor and drawing it lightly in one direction over the fur while yet on the skin. The acid thus acts chiefly on one side of the filaments, and by weakening them on that side disposes them the more readily to bend, double, and change their direction during the operation of felting. The fur thus treated has its colour changed to orange-red, on which account it is known in the trade by the appellation *carroted* fur. That which is imported from Holland is esteemed the best. The only kind of wool admitted into the finest hats is lamb's wool, from Spain or Saxony. It is very carefully washed, scoured, dried, and carded, before it comes into the possession of the hat-maker.

First
process.

The first process in the manufacture is weighing out the requisite quantity of materials for each hat: more than half consists of rabbit's fur, plain and carroted, about one-fourth is wool, and the remainder is made up, according to circumstances, of red wool, and sometimes a little carded silk; but often the only materials are rabbit's fur and lamb's wool. The bowing room has windows only on one side, beneath which is extended a table or counter, divided by partitions into spaces about five feet long, one for each workman. The rabbit fur being thrown in a heap near the left-hand partition, the workman takes a bow, somewhat of the shape of a fiddle-bow, (but with only one string, and much thicker in proportion,) in the work frame; its length is above six feet, and in order to render it more easily manageable, it is suspended by a strong cord. This bow being brought over the heap of hair, the workman gives a strong vibration to the string by striking it with his thumb or with a knobbed stick, the effect of which is to put in motion and completely separate from each other all the hairs that it touches; this is continued till all the lumps and clots are broken down so as to leave the hairs separated and lying as lightly over one another as possible. A light wicker frame, like a common fire-guard, is then employed to sweep the hair a little on one side, in order to make way for the wool, which is bowed in the same manner as the hair, but with a larger bow having a stronger string. The hair and wool are then laid one on the other by means of the wicker frame, and are again bowed till a complete and equal mixture of the two materials has been brought about and an equal distribution has been made over the space that they occupy. The heap is now brought to an even surface by light pressure with the back of the wicker frame, and then covered with an oil-cloth, called a *hardening* skin. Pressure, at first very gentle, and increasing by degrees, is made on the oil-cloth by the hand of the workman, till in a short time the fibres have intermixed, forming a layer which, however, it requires care and practice to handle without tearing. The hardening skin being removed, a piece of damp brown paper, shaped like an equilateral triangle, is put on the layer, the edges of which are folded over so as to cover and enclose the paper except on one side; in this state it is folded up in a damp cloth and worked by hand,

Second
process.

pressing and bending it, rolling it up and unrolling it so as to give every fibre an opportunity of intertwining more or less with those in its neighbourhood, and thus of forming a thin though imperfect and loose felt. The use of the wetted paper is now evident; for without it the conical cavity, which is afterwards to form the inside and brim of the hat, would be obliterated by the mutual felting of the two interior surfaces. This manipulation is called *basoning*, and the triangular *body*, which is the result of it, should be twice as large as it is intended to be reduced to by the next process.

Mechanical
Processes.

The next process is called *planking*. The apparatus consists of a boiler of lead, or lined with lead, surrounded by seven or eight inclined planes of *plank*, each wide enough for a man to work at. The boiler is charged with a mixture of beer-grounds, water, and a little sulphuric acid, which is kept, as near as may be, just on the point of boiling; the workmen have their fingers unprotected, but the palms of the hands are covered with sole leather. The beer-grounds employed by our hat-makers are only a substitute for the lees of wine used in France and other European Countries, and each appears to be efficacious only from the small quantity of acid that it contains. In some of the French manufactories the use of lees of wine is abandoned, and its place is supplied by an equivalent quantity of sulphuric acid, by which the following advantages are said to be obtained: the body is brought to its greatest degree of contraction in a somewhat shorter time, a heat less than boiling is quite sufficient, and the felt comes out of this process much cleaner, being free from the mud which it imbibes from the wine lees, and which when dry becomes a fine dust, which it is often necessary to beat out again. Our own manufacturers might possibly derive the same advantage from discarding the use of beer-grounds. The planking begins by the workman laying the felt body on the plank and sprinkling it with some of the hot liquor; he then rolls it up and unrolls it, pressing on it with the leather that is tied to the palm of his hand; during the whole of this operation it shrinks and becomes proportionally thicker and more compact. It is next dipped for a few seconds into the boiling liquor, and is then rolled and worked on the plank as before, the result of which is a still further contraction and thickening of its substance. Lastly, the scalding is repeated, and the felt is worked and squeezed by means of a rolling pin, called a *walk pin*, till it ceases to contract any further. Thus the act of felting, which was begun in the basoning, is finished in the planking; and consists of rolling and pressing, first very gently and at the common temperature, then with a greater force assisted by the action of warm acid liquor, and, finally, with the greatest force that the workman can apply and at a scalding temperature. The use of the acid is probably to facilitate the solution or removal of any oil or mucus which may be squeezed out from the hairs which, if allowed to remain among them during their working, would impede their tendency to felt. The body is then stoved till it is perfectly dry.

Third
process.

The next process is to put in the stiffening, which is a composition consisting for the most part of a saturated solution of shell-lac in spirits of wine. This is applied by means of a brush to the inner surface of the body, and sometimes to the outer likewise, after which it is again stoved; by this means the felt is impregnated with a resinous substance capable of giving the required stiffness to it, and also of rendering it in a considerable

Fourth
process.

Manufac-
tures.

degree impenetrable by rain or cold water. In the act of drying, some of the lac is generally brought to the surface, making it rough; this is removed by just dipping the body in a hot solution of alkali or borax, which loosens the crust and allows it to be got off by the use of a copper scraper, called a *draw board*. It is then a third time stoved, and when nearly dry is singed by holding it over a blaze of shavings, in order to remove the hair which stands out from the surface of the felt.

Fifth
process.

The next process is putting on the nap or roughing. For this purpose the materials, consisting of half or three-fourths of an ounce of beaver fur and some fine cotton, mixed occasionally with some of the other furs already mentioned, are bowed down, and then by the hardening skin are made into a very tender imperfect felt of the shape of the body intended to receive it, but about three inches longer; a strip of this width being then torn off from the bottom of it, the remainder is just sufficient to cover the body, while the strip is reserved for the under part of the brim of the hat. The roughing being thus prepared, the body is softened by dipping it in the boiler, and is then covered with the roughing, the strip being applied on the lower part of the inside. It is then taken to the plank, and the roughing is fixed to the body by first putting it down with a wet brush, then rolling it in a hair-cloth, dipping it in the hot liquor, and working it about as already described in the felting process, till the whole of the cotton is separated.

This is an operation that requires a good deal of care and experience, as will be evident by considering what happens in the course of it to the hairs that compose the roughing. When first laid on they form a horizontal layer, the individual hairs lying in all directions. As soon as the rolling and pressing begins, each hair is put in motion from root to point, and enters the substance of the felt body. These hairs have considerable stiffness and elasticity, and are moreover not weakened by the application of nitric acid; they therefore proceed in a pretty straight course into the felt, with the substance of which they form a union, but by a sufficiently long continuance of rolling and pressing they would actually pass through the felt and be found on the inside instead of on the outside. When the process has been continued long enough, the hairs will have penetrated by their root sufficiently far to secure them from being drawn out in brushing the hat. Up to this stage of the process the body has merely the shape of a cone, without any resemblance to that of a hat, but the next process, which is *blocking*, begins to bring it into form.

Sixth
process.

This is done by pressing in the cone so as to form it into three or four concentric ridges and furrows; then the point is pressed out by the finger, and as it gets wider the hand is used, by means of which, at length, the cone is drawn out nearly to a cylinder; it is then drawn over a wooden block and tied on, and in this state is ready to be dyed. The ingredients of the dyer's copper are water, sulphate of iron, verdigrise, gull nuts, and logwood; and in this mixture the hats are boiled for some hours, at the end of which time they are found to have acquired an intense and beautiful black. They are first drained and dried, and then are taken off the block and transferred to the *finishing* room. Here the hat is first placed over a jet of steam to soften it, then the crown is strengthened by sticking a piece of scale-board on its under side, and securing it by a piece of linen pasted over it; a block is then put into it, and the

surface is smoothed, and a uniform direction is given to the nap by means of warm and damp hair brushes, and a plush brush called a *velours*; a hot iron is also employed for the same purpose.

Mechanical
Processes.

It is next *trimmed*, that is, the binding, leather, and lining are sewed in; and, lastly, it is *finished off* by being warmed and set up to the fashionable shape. Having thus described step by step the whole process of manufacturing a beaver hat, a few words will suffice for the plate and felt hat.

(1062.) The body of the plate hat is entirely of lamb's wool, either Saxon, Spanish, Kentish, or South Down, and after basoning, previous to being planked, is generally boiled in water and stale urine. The nap or roughing is composed of various furs, from that of the musk rat (which is only inferior to beaver down) to those of the lowest quality, according to the price at which they are intended to be sold. The felt hat is made entirely of wool, without any roughing, the nap being merely scratched up by a card, and the stiffening is glue instead of lac.

Plate hats.

Silk hats, as they are commonly called, were invented some years ago. They are hats with a thin wool body and a nap of silk. But as silk is not capable of felting, it was necessary to discover some other method of fixing it on the body. After many trials, that which has finally been adopted has been to take the silk manufactured into plush, with a pile of unequal length, and to sew it together into a cover just capable of fitting the felt body. This latter is then smeared over with an adhesive resinous mixture, and as soon as it has become dry the bag or cover of silk plush is drawn over it and fixed firmly to the body by means of a hot iron; it is then finished in the usual way.

Silk hats.

(1063.) The last variety of hat we shall mention is one for the manufacture of which a Patent has recently been taken out by Mr. Williams. The body is made of hemp, tow, or of waste silk, finely carded, or rather torn into distinct filaments; but as neither of these substances possess in the slightest degree the property of felting, the following very ingenious and simple method has been employed to form these filaments into hat bodies very even, light, and of greater strength than felt of the same thickness.

Williams's
Patent for
hat-
making.

A fan with vertical fliers is fixed in a case or box, open at top, and united below with a horizontal trunk, in which are apertures that may be opened or shut at pleasure. It is evident, therefore, that if the fan is put in motion, its effect will be to exhaust, to a certain degree, the air in the trunk, the consequence of which will be that a current of air will set in through each of the open apertures. A frame of the shape of a hat, made of sheet zinc perforated with many small holes, is placed over one of these openings, and by simple mechanism a slow motion round its centre is given to it. The carding machine delivers the filaments of silk or hemp into the air above, and a little on one side of the revolving frame. The filaments in their descent soon get into the current of air that is setting into the trunk through the perforations of the zinc frame, and are deposited quite evenly on its surface, and so rapidly, that in about five minutes a layer of sufficient thickness for a hat body is formed. A frame of perforated sheet copper is then put on, so that the layer of silk is enclosed between the two, and, though possessing in itself no coherence, is thus prevented from being in the least degree deranged. The frames are then dipped into a boiler full of a stiffening

Manufac-
tures.

mixture, the chief ingredient of which is shell-lac, and when sufficiently drained the upper frame and afterwards the under ones are removed, leaving the filaments of silk cemented into a hard, light, strong hat body, which is afterwards covered with silk plush in the manner before described.

Various
uses of felt
in the Arts.

(1064.) We have now finished what was proposed to be said on the subject of hat-making, but before concluding this article it will be well to make a few remarks on the other uses to which felt is applied. The polishing wheels of comb-makers, workers in brass, and other artisans, are covered with felt, which, by its spongy texture, retains the putty and other polishing powders better than any other substance would do. The felt for this purpose is made into sheets of various thicknesses, which are afterwards cut up into strips of the required size. Gilders' baskets, in which they shake buttons and other articles of copper with an amalgam of gold, being part of the common process for gilding such substances, are made of felt. An old hat was first employed for this purpose, but it has been found more convenient to have larger baskets made expressly for such use. Some kinds of large filters or jelly bags are now often made of felt; and a kind of paper, made chiefly of wool, is imported from Germany for the use of chemists and apothecaries; it is an excellent filter for hot liquors, acting rapidly, and is not nearly so liable to be broken through with the weight of the liquor as a paper filter. Felt, chiefly in the form of old hat, is likewise extensively used by the engravers of blocks for calico-printers, being inserted in those parts of the pattern where a large body of colour, or, rather of mordant, is to be laid. Old hat is likewise converted into an excellent polisher by dipping it into a weak solution of common alkali and then drying it. The alkali decomposes the black dye, bringing the iron, which is the base of it, to the state of oxide or rust, which remains disseminated through the whole substance of the felt.

Lastly, felt is largely and increasingly employed in sheathing ships. A great quantity of cow's hair enters into the composition of this substance, and as it felts only very imperfectly, the sheets while making are passed through a boiler of pitch or tar, which increases their cohesion. Sheathing felt is applied in coppered ships immediately below the copper. There are two most important benefits attend the use of this sheathing. In the first place, it is a complete protection against the worm, which probably is incapable of working its way against the stiff bristles which are largely introduced into the composition. In the second place, it is impermeable to water, and being at the same time very extensible, is not easily broken by the working which takes place among the timbers of a crazy ship; hence many leaks are prevented which might otherwise damage the cargo, or even hazard the safety of the vessel itself as well as the lives of the crew.

Paper-making.

History of
paper-
making.

(1065.) The Art of paper-making is of great antiquity, and probably of Chinese origin; but at what period the Chinese paper, or the art of manufacturing it, was first known in Europe, is not, perhaps, quite certain; although it is generally supposed that the knowledge of the article itself, and the process of making it, were brought from the East by the Arabs, and that the manufacture was practised in Spain during the IXth or Xth Century.

Mechanical
Processes.

Before the invention of paper, materials formed of different substances were had recourse to for the record of events, and for the common purposes of writing; such as skins, thin sheets of horn and ivory, and the Egyptian and Greek papyrus, formed from a plant bearing that name. These last, however, although used for the purposes for which we now employ paper, partook in no degree of its character in the nature of their manufacture. The skin was merely converted into parchment, and the bark of the papyrus preserved after the removal of the fibre, in nearly its natural form; whereas what is properly called paper is an actual manufacture, a new formed substance, which resembles no way the material from which it is derived, and to this kind of paper only the following remarks will apply.

It has been said that, in all probability, the invention of the Art of paper-making originated in China, and it is stated by Casira to have been introduced at Mecca in 710; but it is certain that the Chinese were acquainted with the Art long before that epoch, but it is not certain whether they were the actual inventors or had derived it from some other people. It appears, however, at all events, that, for a long period of years after they possessed the knowledge of letters, they were unacquainted with the use of any material for writing upon of the nature of their present paper; the first invention of which is said, by some of their authorities, to have taken place in about the year 95 of our Era; that it was due to a Mandarin of high rank named Isay, and that he employed, as the material of the composition, not only cotton and silk, but also the inner bark of different trees. In course of time many other substances have been employed by them, and at present, it is said that not only cotton, silk, and linen rags, but the bark, and even the wood, of the bamboo and cotton tree reduced to dust form ingredients in the manufacture of Chinese paper; and it is now well known in Europe that paper may be formed of almost any kind of fibrous material, although none seems so well calculated for the purpose as the rags of white linen. The history of paper, therefore, stands as follows, viz. that it was probably first invented in China, about eighteen hundred years ago, and it was thence brought to Mecca, with the Art of imitating its manufacture, about the end of the VIIth or the beginning of the VIIIth Century; whence the Arabs transferred it to the Northern coast of Africa and to Spain, where we have seen it was introduced in the Xth Century, or probably somewhat earlier. It is, however, doubted whether the rest of Europe originally obtained their knowledge of the invention from that Country by the way of Asia, or from Constantinople through Greece.

In the XIIth Century it appears to have become the common material for writing upon throughout Europe; but there is great difference of opinion as to the date at which cotton paper first began to be supplanted by that made from linen. According to some authorities, paper was manufactured from linen by the Moors of Spain before the Xth Century; while other writers contend for a much later origin of this improvement. "The manner of making the cotton paper," says Anderson, in his *History of Commerce*, "introduced the still better and cheaper paper made of linen rags. This last invention Montfaucon ascribes to the XIIth Century; yet others make it so late as 1417; and an octavo Treatise in English, entitled *The General History of Discoveries and Improve-*

Manufac-
tures.

Introduc-
tion of the
paper ma-
nufacture
into Eng-
land.

ments, says, that rag paper was not invented till about the year 1452; while Rombold, in his Dissertation on Paper, printed at Berlin in the year 1744, fixes its invention to have been in 1470, though probably somewhat earlier. The cotton paper invented (A. D. 900) very nearly resembled our rag paper; but as the latter was much cheaper in its manufacture, as being made of rags, which before were thrown on the dunghill, it soon drove out of use the cotton paper, which necessarily bore a much higher price."

It was long before the manufacture of paper was introduced into this Country, the first known erection of a paper-mill having been in 1588, at Dartford, in Kent. "But about the year 1690," says the writer we have just quoted in another place, "there was scarcely any other kind of paper made in England, except the coarse brown sort; but the war with France occasioning high duties on foreign paper, the French Protestant refugees settled in England chiefly, and also our own few paper-makers now began to make white writing and printing paper; which in length of time has been brought to so great perfection, both for beauty and substance, that in our own time (1764) we import only certain kinds of Genoa and Dutch paper, which, however, bears but a small proportion to all the paper used in the British dominions. How great a saving this has proved to Britain may partly be conceived from what has been often formerly affirmed by such as are well acquainted therewith, viz., that to France alone, from which we now take none even in time of peace, we paid annually to the amount of one hundred thousand pounds, for paper only." In 1721, according to the *British Merchant* published in that year, two-thirds of all the paper used in England was made at home, and this proportion is said to have amounted to 300,000 reams. "In 1783," says Mr. McCulloch, (*Dictionary of Commerce*, 2d edition, p. 875,) "the value of the paper annually manufactured was estimated at £780,000. At present, besides making a sufficient quantity of most sorts of paper for our own use, we annually export about £100,000 worth of books. We still, however, continue to import certain descriptions of paper for engraving from France, and a small supply of paper-hangings, the duty on both amounting to about £2800 a-year. In 1813, Dr. Colquhoun estimated the value of paper annually produced in Great Britain at £2,000,000; but Mr. Stevenson estimated it at only half that sum. From information obtained from those engaged in the trade, it appears that the total annual value of the paper manufactured in the United Kingdom, exclusive of the duty, may at present amount to about £1,200,000 or £1,300,000; and that we have about 700 paper-mills in England, and from 70 to 80 in Scotland; but the number in Ireland is inconsiderable. Of these mills, few have been lately unemployed, and about 27,000 individuals are supposed to be directly engaged in the trade; but in addition to the workmen employed in the mills, the paper manufacture creates a considerable demand for the labour of mill-wrights, machinists, smiths, carpenters, iron and brass-founders, wire-workers, woollen manufacturers, and others, in the machinery and apparatus of the mills."

In a passage quoted above from Anderson, the substitution of linen for cotton in the manufacture of paper was spoken of as having at first greatly lowered the cost of the manufactured article, but now that cotton has become much more plentiful and much cheaper than

linen, it has been again resorted to, we believe, to a considerable extent, in the manufacture of printing paper, and even of writing paper; its only recommendation, however, is its cheapness, for from the comparative weakness of the fibre in cotton, paper when made from that material has far less strength and durability than when made from linen.

It appears that about four-fifths of the linen rags, from which English paper is formed, is imported from foreign Countries, principally from Italy, Germany, and the United States, the exportation of rags being prohibited in France, Holland, and Belgium by severe penalties; the exportation of rags is also prohibited in Spain and Portugal. The imported rags arrive here in close bags, already sorted, and the bags variously marked, so as to indicate the quality of the rags within; these are taken to the mills, where a further sorting takes place, and the operation of paper-making commences. This is at present in the larger manufactories carried on by machinery, but in some smaller ones by hand. So great, however, has been the advantage of employing machinery, and so great the improvement in the chemical processes to which the rags are submitted for bleaching them, that as much of the latter process is said to be effected at present in three minutes as formerly required as many weeks.

(1066.) *Process of paper-making by hand.*—The general nature of the processes of paper-making, the particulars of which will be given below, consists in separating the fibres of the rags into exceedingly fine and short filaments, by a mill constructed for that purpose, and mixing the material thus reduced with such a quantity of water as will convert the mixture to a fine pulp, which is afterwards taken up in a very thin and even layer upon a mould of wire cloth. Here the water, draining through the wire, leaves the filaments of linen so completely interwoven or felted amongst each other, that they will not separate without breaking, and when dry will form a sheet of paper, the strength and quality of which depends, of course, very much upon the material it is made from, and the equality of length and size to which the filaments are reduced by grinding, which uniformity alone can cause them to float equally in the water of the pulp, and thus distribute themselves evenly and smoothly over the wire mould when taken up by it. Such are the general principles of paper-making by hand, which it will now be necessary to describe more in detail. The entire operation may be reduced to three distinct heads, viz., preparing the pulp, forming the sheets, and finishing the paper.

In the first process the rags are sorted into qualities proper for different purposes; they are then bleached, unless, as is sometimes done, this is deferred to the next stage of the process.

The washing is effected in a mill in which the rags are ground to a coarse imperfect pulp, called half stuff, in which state the bleaching (if it has not been previously done) is effected. The bleaching is also sometimes performed in the mill while the rags are being ground. The half stuff, in this state, is again reduced in what is called the beating engine, and sufficient water is added to convert the whole to fine pulp, in which state it is conveyed to the vat, and is then in a proper condition for being formed into sheets.

When the second process is effected by hand, it is performed by a workman who takes up a quantity of pulp, already placed in a kind of cistern, upon a mould

Mechanical
Processes.

Supply of
rags.

General
process.

Manufac-
tures.

of fine wire cloth, through which the water drains away, and the pulp coagulates into a sheet of paper, being rendered uniform in thickness by a slight shake given to the mould. Another workman now takes the sheet of paper off the wire mould and receives it on a plate of felt; he then covers it with another plate of felt, evenly spread, on which is placed a second sheet of paper; and thus he continues the operation till he has made a pile, called a post, containing six quires of paper. This is now removed to a press and submitted to a strong pressure, which presses out the superfluous water and gives the requisite surface, firmness, and solidity to the paper.

The pile is now removed from the press and the paper taken out sheet by sheet, which, being laid one on the other, are again submitted to pressure in a smaller press, where they remain for a certain time, when they are removed, and are then hung up on lines to dry. This finishes the second process, and for many common sorts of paper it is the last, the article now merely requiring packing for the market; but the better sort of paper for writing, printing, &c. has to be finished, which, as we have seen, is the third process.

In what is called finishing, the paper, in parcels of five or six sheets each, is dipped into a tub of fine size and afterwards pressed to force out the superfluity; it is then again dried in the drying loft; this is not, however, necessary for printing paper, the size in this being introduced at an earlier stage. After this an examination is made of every sheet individually, and all knots and burs are removed, and the defective sheets thrown aside. A large pile is now made of the selected or perfect sheets, which are again submitted to a great pressure to render them flat and smooth; they are then taken from the pile sheet by sheet so as to form them again into a pile without turning them over, by which means new surfaces of the sheets are brought in contact with each other, and the pile is once more submitted to the press and the surfaces of the sheets are further improved; this operation, which is called parting, is repeated two or three times for the best paper, which is then counted into quires and packed ready for the market.

Such is the old process of paper-making by hand, and the principle is the same as regards the constitution of the paper in the modern operation by machinery, which still remains to be described.

Paper-
making by
machinery.

(1067.) *Paper-making by machinery.*—We have passed over, in very concise terms, the general principles of paper-making by hand, and have not described the machinery which, even in that process, is necessary in the preliminary part of the operation, because the same is employed in the modern mill in a more improved form, and we preferred to give all the machinery under this one head; we shall therefore now describe more in detail the entire operation from the first receipt of the rags to the production of perfect paper.

Sorting.

Sorting the rags is of course the same whether the final operations be by hand or by machinery. This is commonly carried on in the sorting room by women, who are placed at tables having wire bottoms through which the dirt from the rags may fall; a knife blade of large size is fixed up across the table; the rags are taken up in one hand, and such as require to be cut are run across the edge of the knife and thus reduced to their proper lengths, and the different kinds separated by being placed in different boxes. These are afterwards examined by an overlooker, who makes a further separation if necessary.

VOL. VIII.

The rags are then dusted in a machine for the purpose, consisting of a wire cloth cylinder about six feet long and four high, into which a certain quantity of the cut rags are placed, and within which are arms or spokes about twenty inches long fixed to the axis; this being set in rapid motion by being put in gear with the machinery of the mill, the rags are driven about with great violence and all the dust in them passes out through the wire cloth.

Mechanical
Processes.
Dusting
machine.

Boiling the rags is the next operation. This is generally conducted in sheds, in which there are several large chests filled with rags, into which steam is forced for the purpose of heating the mass of rags and water; after remaining in this state for some hours, they are in a fit condition for the engine, which is next to be described.

(1068.) The engine consists of a trough A A, plate lxxix. fig. 1, which is about ten feet long, four and a half feet broad, and two and a quarter feet deep; this is made of wood lined with lead. B is a longitudinal division of the engine; C is an iron roller twenty-two inches in diameter, and twenty-six inches wide; and D is an apparatus for conveying pure water into the trough, and for carrying off the foul water. The roller being set in motion, about a hundred weight of rags are put into the trough, and as much water is let in as will raise the whole to within an inch or two of the brim. The roller is not a plain cylinder, but its surface presents a number of bars or knives projecting more than an inch radially from its axis, and beneath the roller is a plate composed of bars or knives, of the same kind as those of the roller, as shown in fig. 2. When the roller commences its revolutions, of which it makes about 160 in a minute, the rags are carried with great rapidity through the knives, and as the roller is depressed upon the plate or elevated the rags are cut or bruised. Above the roller is a cover, (not shown in the figure,) in which are two frames of wire cloth communicating with the pipes at D. When, therefore, the whole mass is in agitation, the rags, after passing through the knives of the roller and the plate, are carried up the inclined plane of the division E, and the foul water passing through the frames is removed by a pipe at D, while a clear stream is continually pouring in from the same point; in this way the rags are bruised down and washed in the first engine. After this operation has been continued for a sufficient time, the water is let off, and the cleansed mass is removed to a press, for the purpose of driving out the greater part of the water which remains in it. In this state the foreign rags, though not white, are clean, and have somewhat the colour of the cloth called brown Holland.

Engine.
Pl. lxxix.
Fig. 1, 2.

It is unnecessary to observe that the rotation of the cylinder is produced by wheelwork connected with the moving power of the mill whether it be water or steam, and that in the larger mills several such engines are at work at the same time.

(1069.) The rags on leaving the engine correspond with what we have called half stuff in our general description. The mass is now, as above stated, taken to a press, and submitted to a great pressure, whereby all superfluous water and moisture is driven out, and is then placed in a close chamber to be bleached.

Bleaching.

This is effected by conveying into the chamber, by means of pipes communicating with a retort, a proper proportion of chlorine gas, common salt, and sulphuric acid, by which process the rags, however originally dyed or discoloured, are rendered perfectly white, but they

Manufac-
tures.

Beating
engine.

are subsequently placed in the washing engine to cleanse them from the chlorine.

From the last stage they are transferred to the beating engine, which resembles in every respect the engine described above, except that the knives and plate are closer together, and the roller in this operation is moved with greater rapidity. After undergoing this process for several hours, the rags assume at last the appearance of perfect pulp somewhat resembling milk, and in this state the size necessary to give a hardness and body to the paper is introduced for some kinds of paper; but for others, particularly writing paper, the size is laid on the surface in a subsequent stage, as already stated.

In the above processes machinery is employed, whether the next operations are to be performed by hand or not; but we shall not add any thing further to the preceding account of hand-made paper, but proceed to describe the modern mill, which is, perhaps, as interesting a piece of machinery as it is possible to imagine. At one end of the machine is a vat of pulp; this is let off into a cistern; from this cistern it is transferred to an endless wire cloth; as this passes along for a few feet the water drains off and the pulp begins to possess a certain consistency and solidity; it now passes through certain rollers, and much of the superfluous water is absorbed; continuing still its forward motion it is submitted to further pressure, its surface is formed, but it is still moist. It now passes over hot metal cylinders and finally emerges from the machine in a continuous length of perfect paper, or it goes still forward, enters the cutting machine, where it is cut into sheets of a proper size, according to the nature of the paper in hand. Such is the general nature of the modern paper machinery, but the reader will expect a more minute description; it must, however, be observed, that the processes differ considerably in different mills, and we must confine ourselves only to one or two of the most approved of them.

Fourdrinier and
Gamble's
Patent.

(1070.) *Fourdrinier's machine.*—This was the first successful attempt at supplying machinery to perform the duties of the deckle or mould, but it did not at first carry the process to the extent we have just described, that is, the paper was not dried on the machine, but was removed to lofts for that purpose; it contains, however, the elements of the present processes, displays great ingenuity, and is still employed; a description of it will therefore be interesting.

The pulp being prepared is placed in a large vat elevated on brickwork, in which are two agitators turned by the machinery of the mill to prevent the stuff settling and to preserve it of the proper consistency; from this vessel it is discharged by a sluice into a cistern, over the edge of which it runs in a fine smooth stream (like water over a river wear) upon an endless wire cloth, the breadth being preserved and the stuff prevented from overrunning the edges by running straps. This cloth, in the first machines, was twenty-four feet long, the part nearest the vat running over a number of small rollers to prevent its sinking and the pulp becoming of unequal thickness; during the passage of the pulp on the endless wire cloth to the extreme roller a great deal of the moisture is discharged, and it has there assumed such a consistency as to receive the impression of the finger without any tendency to restore itself by fluidity. This process, *viz.*, of discharging the water, is facilitated by a shaking motion communicated to the wire cloth by certain arrangements in the machinery which also equalizes the thickness. The water thus discharged

contains a certain portion of the pulp, and is caught in a shallow cistern below the wire cloth, and is thence transferred to another vessel, from which it is raised by an axle carrying scoops or scuppers, and taken thence back to the vat. This part, however, is not introduced into the recently constructed mills, the operation being effected in a more simple way. When the paper has arrived at the last roller, or at the end of the wire cloth, it passes between two rollers and then falls on a web of felt which carries it exactly as the wire cloth had done, and at the end it again receives another pressure in passing with the felt between two rollers; by this means a great portion of the remaining moisture is absorbed, the paper being in a state to be wound upon a reel. When sixteen or eighteen quires have been thus accumulated, the reel is removed and another substituted, the paper is cut off the first reel and sent to the loft to dry. There are a great many other appendages, &c. described in Messrs. Fourdrinier and Gamble's Patent which we think it unnecessary to describe; amongst others, circular shears for cutting the edges of the paper and for dividing it into sheets of a proper size, &c. Great ingenuity is displayed in the whole of the arrangement; experience, however, has certainly enabled subsequent constructors to simplify several of the parts, but the principle of the operation has been preserved in them all except the machine of Mr. Dickinson, which acts by means of a vacuum, after a manner we will now endeavour to describe.

(1071.) The principle adopted by Mr. Dickinson, and which, in consequence of subsequent improvements, has been the subject of a great number of Patents, consists in causing a cylinder covered with wire cloth to revolve over and just in contact with the prepared pulp, so that by a connection of this cylinder with an exhausted vessel the pulp, which adheres to the cylinder in its passage over the surface, is gently pressed and the paper rendered drier and of more uniform thickness than in the former machine. The many additions and alterations, however, which have been made by the ingenious inventor prevent us from attempting any thing like a minute detail of them; we shall content ourselves therefore with describing the general principle, and an account of his Patent of May 1811. A general idea of the cylinder will be understood by referring to fig. 3, where A is a hollow revolving cylinder made of brass and polished outside and inside. On the surface B C a great number of small holes are cut in the cylinder, and over these holes a wire cloth is neatly secured, the stuff or pulp fills the vessel d, and the water runs into the cylinder as it revolves and leaves a portion of pulp on the wire cloth. The parts E, E form a box in the cylinder which does not revolve, and the edges of the box F F touch or rub against the interior of the cylinder; c is a pipe connected with the receiver of an air-pump which exhausts the box G. When the wire cloth with the pulp on it arrives above the exhausted space G, the pressure of the atmosphere presses the pulp on the wire cloth, thereby giving to it a certain consistency and regularity. The cylinder H, made of a hard body covered with felt, then receives the sheet; when it reaches the point I it adheres more to the cylinder H than to the wire cloth; it is then pressed between the cylinders H and K and taken off at L, and finished in the usual way. This is sufficient to give a general idea of the difference of principle between this method and that of the original inventor Fourdrinier.

Mechanical
Processes.

Dickinson's
Patents.
Pl. lxxix.
Fig. 3.

Manufac-
tures.

But much has been done by Mr. Dickinson to improve his first discovery, which has formed the subject of several Patents, one of which, 1809, is perhaps the best for giving a more complete idea of his operations; this specifies seven distinct improvements, the first of which is a different way of forming the openings into his cylinder. In the preceding statement the surface of the cylinder is described as containing a number of small holes; this is altered in the present case by making the openings in another way, but to the general reader the difference is not important; we shall not, therefore, enter into particulars.

Fig. 4.

The second improvement described in this Patent consists in a more perfect mode of removing the water from the cylinder above spoken of. The ends of the cylinders having holes in their middle turn on the tube G, fig. 4; this tube has an arch or quadrant at each end within the cylinder H H to which the trough I is fixed at each end; and the tube arms and trough being all likewise firmly fixed, the cylinder in turning round will rub on the top of the trough, which should be provided with a packing of leather or other soft substance. In the upper part of the tube G there is an opening which communicates through the pipe K with the exhausted trough I and exhausting vessel worked by a pair of double-acting air-pumps. The tube G is intended for letting out the water from the inside of the cylinder instead of its running out at the ends, as proposed in the former Patent. The pipes L, L, &c. are open at their lower ends, and soldered or otherwise fixed into the tube G, which has no opening except through the cocks J, J, the orifices of which are below the mouths of the pipes L, L, &c., and consequently the whole together will act as a syphon and empty the cylinder as low as the mouths of the pipes L, L, or when the cocks J, J are shut the water which is admitted into the inside of the cylinder through the surface cannot pass out through any channel. The intent of this part of the apparatus is that the water inside the cylinder may be kept to any level between the bottom of the pipes L, L, and the height of the pulp on the inside of the cylinder, by the cocks J, J being more or less turned, and the pressure of the head of pulp on the cylinder, and the quantity of water forced through it, may be adjusted accordingly; and as the thickness of the paper depends on the quantity of fibres of rag left on the surface of the cylinder by the water flowing through it, this principle affords the means of regulating it with great precision. The exact shape of this part of the apparatus is not material, but the tube and cocks must be of large diameter, as the quantity of water that flows through in making paper by this method is very considerable.

Fig. 5, 6.

The third improvement relates to the construction of the vessel intended to contain the pulp for the supply of the cylinder. This vessel is represented in fig. 5, 6 with the cylinder in the inside of it; and instead of the cylinder rubbing against it, as formerly described, it is proposed for the cylinder to turn round in it without touching it, a motion being communicated to the former by means of a toothed wheel, which works on the tube G for an axis, and has a clutch attached to the boss which connects it with the cylinder. In the longitudinal section, fig. 5, the vessel is observed to hang on one side on the boss of the toothed wheel N, and on the other side on the tube G, and between the joints rings of leather are put to prevent the pulp or water escaping; or any other well-known method of packing

Mechanical
Processes.

may be used for that purpose. There is a piece of metal on each side of the vessel or back, shown in fig. 5, which is fixed by screws, and is intended to take off, for the purpose of getting out the cylinder, &c., when it is necessary to take the machine to pieces. The direction in which the cylinder works is shown in fig. 5, by arrows, and as the water is constantly running through the cylinder and out of the cocks J, J, fig. 4, while the machine is going, the fibres of rag are accumulating on any given part of the surface during that period of its revolution, while it is passing from the point Q to the point R, and at the point S, after the paper collected on the cylinder has passed over the trough, and has been sucked nearly dry, it is led off the cylinder by the couching roller T, to which it will adhere; the exact shape of the back is not material, and the method of giving motion to the cylinder may be varied, but that described in the drawing will be found most eligible in use. The back may be of wood or metal; copper has occasionally been made use of for this purpose. The object of this improvement is to remove the friction between the back and the cylinder, and to employ as large a proportion of the surface of the cylinder as possible in the accumulation of the pulp, so that the quantity necessary for the formation of a sheet of paper may be collected upon it in a shorter space of time than by the original method, and consequently the machine enabled to go at a greater rate. Mr. Dickinson's fourth improvement relates to the process of couching, or taking the paper off the cylinder, in lieu of the brass roller used for that purpose, as described in Mr. Dickinson's former specification, dated July 19, 1810; instead of which he now recommends a roller covered with several folds of woollen cloth, so that the surface is moderately soft and elastic. It is to be observed that the caps are made so as to fit on to the bevel at the ends of the cylinder, in such a manner that their outer surface stands exactly flush with the outer surface or periphery of the cylinder; and the couching roller T should be made rather longer than the cylinder, and the ends of the spindle worked in a grooved bearing, so that the roller may only be confined down upon the cylinder by its own weight, or by suspending equal weights at each end of it, in case its own weight should not be sufficient.

The fifth improvement alluded to by the author consists merely in the application of a well-known method of using an endless felt, which is shown in fig. 5, marked M. This felt is made to run round the couching roller T, by the pressure of which the paper is caused to adhere to it at the point S, and the paper is carried round with the felt, and receives two subsequent pressures between the pressing rollers V, V and W, W, after which it is reeled off for cutting. The Patentee makes use of two pairs of pressing rollers, the first pair of which takes only a part of the water out, because if the whole quantity were squeezed out at once, it would require the machine to move at a slow rate. The adjustment of the pressure of the first pair of rollers is necessary to be attended to, and is effected by weights hung at each end of the spindle of the top roller and that of the second pair by screws. It is to be observed that it is necessary to use a second endless felt, in order to prevent the paper sticking to the top roller V, as is shown by a line in the figure, and marked X; both these felts may be guided by any of the methods at present in use.

Manufac-
tures.

The sixth improvement relates to the method of feeding. The stuff, properly prepared and diluted with water, is delivered by one or more feed pipes *e* into the back, in such manner that the orifice of the feed pipes is below the surface of the stuff in the back. The vat should be furnished with a sluice, or some well-known method of regulating the supply of stuff through the feed pipes *e*, so as to cause as little stuff as possible to run over the waste pipe *f*. In the longitudinal elevation, fig. 5, *Y* represents a roller which works in a grooved bearing in a pit under the machine, and the weight of this hanging on the felt which goes round answers the purpose of stretching it, or the same may be done by any common well-known method. The felts should be washed while the machine is at work; and the manner adopted for the bottom felt *m*, used by the Patentee, has been to pour water upon it out by the rollers *z, z*, before it again comes in contact with the paper at the point *S*. There is no precise standard for the dimensions of the cylinder and other parts of the machine, which, in conformity to the scale of the figure, may be worked at the rate of forty-eight feet per minute, and even more. The motion may be applied to the machine by any convenient power, and by any method that causes the pressing rollers, the couching rollers, and the cylinders to move at the same rate; this is done by communicating a motion to the spindle of the bottom pressing roller *W*, fig. 5, 6, in the direction described in the drawing by arrows; and upon the spindle is fixed a chain rigger *a*, which, by means of the endless chain *b*, gives motion to the other chain rigger *c*, the spindle of which turns the toothed wheel *d*, which works into the toothed wheel *N*, and by means of the clutch before mentioned, which connects the wheel *N* with the cylinder, the latter is turned round in the direction shown in the figure. The endless felt *N* being put in motion by the pressing rollers *W, W*, will by its friction give motion to the other rollers and the upper felt *X*. It is to be observed that the suction from the trough *I* must be continued while the machine is at work, by the action of air-pumps, the construction of which is well understood and has long been practised; but they must be worked in such manner as not to exhaust too much air nor too little, and the motion adjusted accordingly. The letters of reference to the different parts of the machine are the same in the different figures.

The author's last improvement consists in certain alterations of the back, so as to enable the machine to make paper having two or more different colours in the same sheet. For this purpose the back must be partitioned off, according to the description of the paper it is required to make; that is to say, supposing it is intended to make paper having various stripes of different colours down the sheet; to accomplish this, it is necessary to have different vats or feeding vessels for each different colour of the stuff, with corresponding partitions in the back. We do not, however, consider a description of this part essential to our present article.

Different
sizes and
denomina-
tions of
paper.

(1072.) Prior to the commencement of the last century there was no duty on paper, and the sheets were made of various and uncertain size; each maker, however, distinguishing his own by introducing his name or some device into the paper, by working fine wire into the mould in which the sheets were made, the impression of which remained when the sheet was formed, as is still

practised; and from this circumstance the names of some sorts of paper derived their origin, as for example, *foolscap*, which was so called from the maker of that sized sheet, now commonly employed for business, having used the device of cap and bells. Paper is now made more uniformly of the same size, and receives particular denominations, as foolscap, post, demy, &c.; drawing paper has also similar denominations, depending on its size, as stated below.

	Ft.	In.		Ft.	In.
Wove antique	4	4	by	2	7
Double elephant	3	4	„	2	2
Atlas	2	9	„	2	2
Columbus	2	9 $\frac{3}{4}$	„	1	11
Elephant	2	3 $\frac{3}{4}$	„	1	10 $\frac{1}{2}$
Imperial	2	5	„	1	9 $\frac{1}{4}$
Super royal	2	3	„	1	7
Royal	1	10	„	1	6
Medium	2	0	„	1	7

A duty was first laid on paper by Statute 10 Anne, c. 19: and, after undergoing various changes, it was fixed, in 1803, on the footing on which it stands at present, but an alteration is at this time under the contemplation of the Government. By the Statute 43 George III. c. 69, it is enacted that

£. s. d.

For every pound weight avoirdupois of paper made in Great Britain, (the duties in Ireland have long been identical or nearly so with those in Britain,) of the first class or denomination, that is to say, all paper, other than brown paper, made of old ropes or cordage only, without extracting the pitch or tar, or any part therefrom, and without any mixture of other materials therewith, and not being glazed paper for clothiers and hot-pressers, or sheathing paper, or button paper, or button board. . . 0 0 3

For every pound weight avoirdupois of paper made in Great Britain, of the second class or denomination, that is to say, all brown paper made of old ropes, as afore said 0 0 1 $\frac{1}{2}$

Pasteboard and millboard are charged with the duty by the hundred weight as follows:

All pasteboard made from paper of the first class 1 8 0

Pasteboard made from paper of the second class 0 14 0

Millboard, sheathing paper, glazed paper for clothiers and hot-pressers, button paper, and button board 1 1 0

All coloured, printed, or stained paper is also charged with a duty of 1 $\frac{3}{4}$ d. per square yard over and above the duty of 3d. per pound charged on such paper in its plain state.

The following Table shows the annual duty on paper, rags, &c from 1820 to 1831.

Manufactures.

TABLE, showing the amount of Revenue on Paper.

Years.	Pounds Weight of First and Second Class Paper.	Pounds Weight of Millboard and Pasteboard.	Amount of Duty of Paper, Millboard and Pasteboard.
	lbs.	lbs.	£.
1820	44,539,509	32,491	474,055
1821	48,204,927	36,253	507,927
1822	51,312,606	38,084	569,189
1823	54,214,611	38,241	592,006
1824	57,760,949	43,518	643,146
1825	62,106,933	48,394	693,188
1826	49,744,993	35,597	546,510
1827	60,040,287	43,257	665,509
1828	64,544,803	49,044	723,497
1829	59,404,709	45,648	681,197
1830	63,686,802	48,579	687,808
1831	62,738,000	42,468	677,104

Report on the paper duties.

(1073.) The policy of these duties on paper has been much questioned, and a Report has recently been made by the Commissioners of Excise Inquiry, and the following abstract of this Report by the Secretary of the Board contains certainly many important remarks. English-made paper was first charged, as above stated, with duty in 1711, the 10 Anne, c. 19.

"The duties on paper were first levied in Ireland by the 38 Geo. III. c. 5, and were charged by a rate on the machinery employed in the manufacture. They were assimilated to the duties in Great Britain by the 5 Geo. IV. c. 55.

"The gross receipt of duty in 1834 was £833,822 12s. 4d., the net receipt £771,162 13s., from which latter sum the charges of the collection are to be deducted.

"A drawback of the whole duty is allowed on all paper made in the United Kingdom on exportation; and by the 43 Geo. III. c. 69, and 5 Geo. IV. c. 55, allowances of duty were granted to clothiers, hot-pressers, and to the Universities, which amounted, with the drawback in 1834, to £62,659 19s. 4d.

"A licence duty of £4 is charged on all manufacturers of paper.

"The Commissioners advert to the important advantage which is enjoyed by the paper-makers under these regulations, viz., that, unlike other growing duty traders, they have 'the process of their manufacture exempt from Excise interference,' to which exemption the Commissioners attribute 'the very great progress which has been made in the application of various improvements to this manufacture, especially those arising from the extensive introduction of machinery, which have enabled the manufacturers, by combining the two processes of making and drying the paper through the operation of large cylinders heated by steam, to complete in a few minutes a quantity of paper which formerly occupied a period of as many weeks.'"

"Injurious effects of the separation of paper into two classes.—The separation of paper into two classes by the 43 Geo. III. c. 69, with two rates of duty, appears, from the concurrent testimony of almost all the witnesses examined upon the point, to be attended with the most injurious effects. This separation was effected by the 43 Geo. III. c. 69, by which it was enacted that all paper and pasteboard should be considered first

class, and subject to 3d. per pound duty, unless made wholly out of old tarred rope and cordage, without extracting therefrom the pitch, or tar, or any part thereof, and without any mixture of other materials therewith.

"It appears from the evidence of Mr. Dickinson, the chairman of the deputation of London paper-makers, and himself an eminent and extensive manufacturer, as well as from that of Mr. Gater and Mr. Gaussen, also considerable manufacturers, and which is confirmed by the deputation of paper makers at Glasgow,—

"1st. That old tarred rope, which during the war, and before chain-cables came into use, was worth £4 to £5, or less, is now worth £11 to £12 per ton.

"2dly. That while old tarred rope has so much increased in price, some sorts of first-class materials have so much declined in value as to be worth only £3 10s. to £4 per ton.

"3dly. That it has been found practicable, without extracting the pitch or tar of the old rope, completely to neutralize the smell of it; the result of all which is that that which, at the time the law was settled, formed a good practical distinction between first and second class papers, has long ceased to be so; and that a very extensive evasion of the law, by the use of first class materials in second-class paper, is the consequence.

"The department of Excise acknowledge that frequent complaints and disputes arise upon the subject; that it is difficult to distinguish between the two; and that one rate of duty would be infinitely preferable to two.

"It is almost superfluous to add, that the continuance of the present classification is condemned by the Commissioners of Inquiry, as calculated to produce consequences highly injurious both to the manufacturer and to the revenue."

"Injurious effects of the high duty on the first class paper.—The injurious effects produced by the present high rate of duty on first-class paper is the next point adverted to; in reference to which, in consequence of the decline which has taken place in the price of paper, the rate of duty is described as amounting now to double what it was, and as forming a great check on the consumption of paper, as well as a great inducement to avoid paying the duty; the rate of profit therefore to the manufacturer has been reduced so low, by the competition with the smuggler, that a very large proportion of the capital vested in mills and machinery is represented as affording no return. On the inferior descriptions of wrapping paper the rate of duty is stated to be not less than 200 per cent., and on the finer sorts, such as printing paper, it is fifty per cent.

"The frauds on paper in Ireland are stated by Mr. Saurin, the Solicitor for Ireland, and by Mr. Plunkett, the Inspector of the Revenue Police, and Mr. Ryan, the Collector for Londonderry, to exist to an enormous amount.

"The prejudicial effect of the high duty in reference to paper used in the printing of books is forcibly demonstrated by the Commissioners of Inquiry, and is illustrated by reference to Mr. M'Culloch's *Commercial Dictionary*, and to the evidence of Messrs. Knight and Parker, the publishers of the *Penny* and *Saturday Magazines*.

"The demand for books is stated to be so extremely uncertain, that in a case where a publisher calculates, from the best information, the probable sale of 1000

Mechanical Processes.

Manufac-
tures.

copies of a Work, he perhaps does not sell 500 copies, or even so many as 250 copies. The duty, however, has been paid on the whole 1000 copies, and therefore adds materially to the loss resulting from the speculation.

"The duty on the paper employed in a Work such as the *Penny Cyclopædia* is estimated by Mr. Knight at one-fifth of the whole; and he states that such a speculation, which now pays at 50,000 copies, would, if the duty were reduced one-half, pay at 40,000 copies, and, if entirely repealed, at 30,000 copies.

"Mr. Knight further expresses his opinion, that a considerable reduction of the paper duty would call numerous such works into existence.

"The operation of the duty on the ordinary volume is estimated by the London deputation at from 1s. to 2s. 8d. a volume, according to the sale.

"The proportion of paper used in printing is estimated as exceeding two-thirds of the whole.

"The Commissioners of Inquiry justly observe, therefore, 'that a large reduction of duty will be materially felt, precisely in that branch of the manufacture to which it is desirable that relief should be afforded.'

"The effect of the repeal of the duty on almanacs, which amounted to 1s. 3d. on each almanac, is very remarkable. No less than 200 new ones are described as having immediately started, of some of which upwards of 250,000 copies were sold within a short period, although the old ones maintain their ground; and Moore's Almanac is stated this year (1834) to have actually doubled its former sales.

"The result of the evidence received, and the observations of the Commissioners of Inquiry in the several parts of the United Kingdom, is stated by them to be 'that the duties, at their present rate and mode of charge, have a most injurious tendency, both in creating temptations to evade the law, and also in checking the consumption of an article which would otherwise be in demand for all classes of the people.'

"As a remedy for these evils,' the Commissioners recommend 'that the present division of paper into two classes should cease, and that so long as that manufacture shall continue subject to an Excise duty, such duty shall be levied at an uniform rate; and that the present rate of first-class paper should be reduced one-half, and accordingly that 1½d. per pound should be fixed as the whole amount to be levied on paper of all descriptions;' and further, that the present separate classes of paste-board should in like manner be consolidated and reduced, and subject to one duty of 14s. per cwt., that rate of duty to be also payable on millboards and other boards, which now pay a duty of £1 1s. per hundred-weight.

"The manufacturers calculate that a very small loss of revenue will result from these measures. The net produce of the duty on first and second-class papers, in 1834, was £718,043, from which, if the duty on second-class paper be deducted, viz. £101,023, there will remain £617,020. Mr. Gaussen calculates that not more than £150,000 of the above sum would be lost in the first year, and that every year afterwards that loss would become less. The London deputation estimate the 'amount which would be received by the Excise, after the consolidation of the duties on first and second-class paper, at £680,000,' leaving a loss of revenue of only £62,980.

"The Commissioners of Inquiry advert to a complaint which appears to have been made by the deputations of

paper-makers both in Edinburgh and Glasgow, of the loss and inconvenience arising from missing opportunities of conveyance, to which they are frequently subjected by the regulation which requires them to retain their paper on the premises for twenty-four hours after the departure of the officer who had weighed it and charged it with duty. The English manufacturers, as well as the officers of Excise, are opposed to the alteration of this regulation, on the ground 'that a shortening of the period would open a door to evasion of duty.'

"The Commissioners of Inquiry consider it inexpedient to dispense with this regulation during the continuance of the present rate of duty; but in deference to the 'strong feeling which the whole of the Scotch manufacturers have expressed upon the subject,' they suggest that 'some relaxation as to time may be allowed as soon as the duties are reduced and consolidated into one.'

"Penalties.—The Commissioners of Inquiry recommend a revision and reduction of the whole of the penalties established by the laws relating to paper, upon the grounds that 'the original penalties in the Act of Anne, establishing the duty, in no case exceeded £50, and were generally very much below it;' and that enormous penalties do not and will not check smuggling, so long as the temptation afforded by high duties exists.' The Commissioners specially allude to one penalty of £200, which is inflicted by the 1 Geo. IV. c. 58, sec. 6, for every label delivered to the manufacturer by the Excise, for which he cannot account. The utmost loss of revenue consequent upon the loss or misuse of the label being the amount payable upon one ream of paper, which, in the case of writing and printing paper, would be from 5s. to 6s. 3d., and on a ream of millboard 25s. The Commissioners suggest that a penalty of 40s., or at most £5, would be quite sufficient to prevent fraud on this point.

MISCELLANEOUS MECHANICAL PROCESSES.

We have endeavoured to classify, as far as possible, the several mechanical processes described under this part of our Treatise, and to reduce them into something like their natural order. The two principal divisions are now completed, i. e. mechanical processes on metals, and the manufacture of fibrous materials. Others which fall under neither of these heads will form the subject of this third and last section, and, being of a very miscellaneous nature, they are collected and given under the above title.

Printing.

(1074.) Under this head we shall confine our remarks and description to the Art of printing from movable types, by the common press and by machinery, and stereotype printing; but in the two following articles we shall endeavour to illustrate the nature of copper-plate printing and lithographic printing. Printing linen, cotton, &c., is already described, (Art. 774, *et seq.*)

The Art of printing in Europe is comparatively a modern invention; it has not at least been known for more than four hundred years; but it appears that printing was practised in China nearly two thousand years back, although not with movable types. This, therefore, would hardly seem to claim our attention in this article, according to the meaning we have affixed

Printing in
China.

Mechanical
Processes.

Manufac-
tures.

to the term printing; but as it was employed in the printing books, &c., it may, perhaps, be with some propriety slightly described in this place, particularly as it remains in the same form in use amongst them to the present day. Their process is as follows. They take blocks of wood, firm, close, and smooth, of the form and size of the page they mean to print, on the one side they glue a paper, on which some able penman delineates the necessary letters and characters; the wood in this state is put into the hands of a sculptor, or rather wood engraver, who, following with proper tools the outlines of the characters inscribed on the paper, cuts out the other parts, leaving the letters in relief; the paper then is gently removed, and the engraved tablet thus prepared is that by which their printing is executed. The disadvantages of this mode of execution are manifest, as there must be as many blocks as there are pages in a book, and they are of course useless in printing any other Work; besides, the process is extremely tedious and expensive. The Chinese Chronicles state that this mode of printing was discovered in China about fifty years before the commencement of the Christian Era, and we have seen (Art. 1065.) that the manufacture of paper was first introduced by them about ninety-five years after the same; so that printing amongst these people preceded paper-making about one hundred and forty-five years, during which period they printed on silk cut into leaves of proper dimensions.

It may be remarked that, to counterbalance in some measure the disadvantages of this method of printing, the Chinese books are free from any errors of the press, are very accurate, and extremely beautiful, the best penmen only being employed for this business; but, on the other hand, both their paper and ink are bad, so that a very old book is seldom to be met with in China.

(1075.) From what has been said, it appears that the Chinese process is rather a species of printing from plates than from types, and whether we derived our Art of wood-engraving and printing from them or not it is now difficult to say; but we certainly did possess that Art before the use of types was known; playing cards, for the amusement of Charles VI. of France, having been thus printed during the latter part of the XIVth Century, whereas the discovery of the Art of printing by types was not made before the XVth Century. To the impression for cards succeeded various devices and characters, with some lettered descriptions, printed only on one side, but which, by afterwards pasting the blank sides together, formed a kind of book; of these first Works, it is believed, some still exist. It appears that in Earl Spencer's library is a specimen of this kind of printing as early as the year 1443.

Great controversy has been carried on respecting the author or inventor of the present Art of printing; but as this question has been examined at considerable length in our alphabetical division, it will not be necessary for us to recur to it in this place; we shall therefore simply observe, in reference to the mechanical improvements in the Art, that it is now about 300 years since the publication of the first Bible, and from that time to about the commencement of the present century no new principle was introduced. That there was a general advance in the neatness of execution and in the taste with which successive Works were got up, is not denied, but the principle remained the same; so also in the form of the press, a lightness and elegance of struc-

ture succeeded to the ponderous and shapeless German press, paintings and engravings of which are sometimes to be met with; still, however, its principle of action remained unchanged, as well as the method of inking the type, on the accuracy of which latter process the great beauty of modern printing, in comparison with the old, consists, and the difference is very striking.

"The early printers were frequently governed by the wish to make their printed pages bear a resemblance to the old manuscript books formerly in use; and upon the whole much less taste was displayed, in respect of neatness and accuracy, than might have been expected from the intelligent class of men who first cultivated the "divine art." The following particulars relative to the early productions of the press will show how the style of book-printing was gradually improved: "With respect to their forms, they were generally either large or small folios, or at least quartos: the lesser sizes were not in use. The leaves were without running title, direction-word, number of pages, and divisions into paragraphs. The character itself was a rude old Gothic mixed with Secretary, designed on purpose to imitate the handwriting of those times, the words were printed so close to each other that they were read with difficulty, even by those who were used to manuscripts and to this kind of letter, and often led the inattentive reader into mistakes. Their orthography was various, and often arbitrary, disregarding method. They had very frequent abbreviations, which in time grew so numerous and difficult to be understood that there was a necessity of writing a book to teach the manner of reading them. Their periods were distinguished by no other points than the double or single one, that is, the colon and full point; but afterwards was introduced an oblique stroke, thus /, which answered the purpose of our comma. They used no capital letters to begin a sentence, nor for proper names of men or places. They left blanks for the places of titles, initial letters, and other ornaments, in order to have them supplied by the illuminators, whose ingenious Art, though in vogue before, and at that time, did not long survive the masterly improvements made by the printers in this branch of their business. Those ornaments were exquisitely fine, and curiously variegated with the most beautiful colours, and even with gold and silver; the margins, likewise, were frequently charged with variety of figures of saints, birds, beasts, monsters, flowers, &c., which had sometimes relation to the contents of the page, though often none at all. These embellishments were very costly; but for those that could not afford a great price, there were more inferior ornaments, which could be done at a much cheaper rate. The name of the printer, place of his residence &c. were either wholly neglected, or put at the end of the book, with some pious ejaculation or doxology. The date was likewise omitted, or involved in some cramped, circumstantial period, or printed either at full length, or by numerical letters, and sometimes partly one and partly the other; thus one thousand CCCC and lxxiii, &c.; but all of them at the end of the book. There was no variety of characters, no intermixture of Roman and Italic, which are of later invention, but the pages were continued in a Gothic letter of the same size throughout. They printed but few copies at once, for 200 or 300 were then esteemed a large impression; though, upon the encouragement received from the learned, they increased their numbers in proportion."

Mechanical
Processes.

First print-
ing in Eu-
rope with
blocks.

Recent im-
provements
in printing.

Manufactures.

"About 1469-70, alphabetical tables of the first words of each chapter were introduced as a guide to the binder. Catch-words (now generally abolished) were first used at Venice, by Vindeline de Spire. Early printed books had no signatures. Signatures are those letters of the alphabet which are put at the bottom of the right-hand pages of sheets to distinguish their order. When the alphabet is finished, a second begins A a, or 2 A, instead of a single A; and when that is terminated, A a a, or 3 A, begin the third, and so on. In order to indicate more correctly the order of each sheet, printers add figures to the initial letter on the third, fifth, and seventh pages; the numbers of these figures, which do not pass the middle of the sheet, point out the size of the edition. Thus, A 2 on the third page, A 3 on the fifth, and A 4 on the seventh, show a work to be in 8vo.; in the 12mo. size, A 5 on the ninth page, and A 6 on the eleventh page, &c.; but it is now customary to give signatures only on the first and third pages of 8vo., and on the first, third, and fifth pages of 12mo."

In some modern French Works, figures are substituted for letters, and the other leaves are marked by asterisks. The invention of signatures is ascribed by M. Marolles to John of Cologne, who printed at Venice in 1474; the Abbé Rive attributes it to John Koelhof, a printer at Cologne, and contemporary with the former, from whom we have a Work of an earlier date. It is, however, of little consequence who was the inventor, for, on the whole, signatures are rather a clumsy expedient, merely to direct the binder in folding the sheet, and are generally much too conspicuous upon the pages.

One of the chief improvements in the style of typography has been the dismissal of abbreviations and connected letters from the founts. Formerly abbreviations were very common, the word *they* was indicated by the letter *y* and a small *e* above it: the conjunction *and* was indicated by &, which is a contraction of *et*. There were many of this species of abbreviations in printing both the English and Latin languages, and these were not more unseemly than the connected letters; such, for instance, as the junction of the letters *c* and *t* by a curve stroke from the top of one to the other. In recent times, all these connected letters have been disused, with the exception of *ff* and *fl*, and these are only continued because the head of the common *f* would press against the *l*, and be broken. Another very great improvement has been effected in the dismissal of the long *s*, in case of two of this letter coming together.

Printing machines.

It is not, however, merely in matters of taste that printing has been improved, the mode of operation has been in many cases superseded. All our manufactures and machinery have, during the present century, made a great advance, of which we have had frequent occasion to speak in the course of the present Treatise, and that of the printing press has not been neglected.

The great and general increase of education and spirit of inquiry which had spread amongst the English called for some more prompt means than the old press afforded for expediting the news of the day, and this was no sooner felt than it was supplied by the invention of the printing machine, which produced copy after copy to almost any extent. Of these machines we shall speak more in detail in a subsequent part of this article after describing the usual process; they are merely referred to here as an important feature in the printing Art. Still,

however, these machines, powerful as they were, were not all that the state of English society required. To increase their speed of production two or more such machines must be worked, and other copies in type must be set up, which required either a greater time or an increased number of hands. This led to the Art of stereotyping; that is, one complete copy of the paper being set up, an impression is immediately taken from this in plaster to form a matrix in which as many copies may be made as the urgency of the business requires, and as many machines put in action. This method will also be described more at length in a subsequent page. It has, perhaps, brought the Art of printing to its greatest possible perfection.

(1076.) *Process of printing.*—We have hitherto attended only to the early progress of this important Art; it remains for us now to give some description of the several operations. Under Art. 929. is given an account of type founding; we are therefore now to suppose that types are already provided for the printer's use. Each individual class, viz. of letters, points, &c., being of the same height, and distinguished from letters of another class by one or more nicks or notches, which range evenly when the types are set, which, as we shall see, is very convenient in guiding the compositor. There are, in the present day, a great variety of sizes for types to the extent perhaps of forty or fifty, enlarging by a progressive scale from the most minute used in printing pocket Bibles to the largest seen in posting-bills in the streets. Many of these have a distinct name; the smallest is called *diamond*, then follow in gradation upwards, *pearl*, *ruby*, *nonpareil*, *minion*, *brevier*, *bourgeois*, *long primer*, *small pica*, *pica*, and *english*; the larger sizes generally take their names thus, *two line pica*, *two line english*, *four*, *six*, *eight*, or *ten line pica*, &c. Other nations have adopted different designations for their letters, principally from the names of their inventors. All kinds of types are sold by the founders at a price per pound varying in amount with the size of the letter; the smallest size, diamond, costing about 12s. per pound, brevier about 3s. 6d., English 2s., and so in proportion for all intermediate sizes. These prices may appear great, but when it is known that in the diamond size 2800 go to the pound in the letter *i*, and of the thinnest space about 5000, they will not be considered exorbitant.

A complete assortment of types is called a *fount*, which may be regulated to any extent. Every type-founder has a scale, showing the proportional number of each letter required for a fount; but it may be observed that every language requires a particular scale. For the English language, the following is a type-founder's scale for the small letters of a fount, of a particular size and weight, viz.

a	8,500	j	400	s	8,000
b	1,600	k	800	t	9,000
c	3,000	l	4,000	u	3,400
d	4,400	m	3,000	v	1,200
e	12,000	n	8,000	w	2,000
f	2,500	o	8,000	x	400
g	1,700	p	1,700	y	2,000
h	6,400	q	500	z	200
i	8,000	r	6,200		

It will be seen from this scale that the letter *e* is used much more frequently than any other letter. The English type is said to be at present superior in point of neatness

Mechanical Processes.

Different kinds of types.

Manufac-
tures.

and elegance of form to those of any other Country. For this characteristic they have been much indebted to William Caslon, who was originally an engraver of ornamental devices on the barrels of fire-arms and on bookbinders' tools. The neatness with which he executed these works brought him into notice, and he made his first essay as a letter-founder in forming an alphabet of Arabic letters for an edition of the New Testament, about the year 1720. Before that time, the types used in England had been mostly imported from Holland; but the decided superiority of Caslon's letters over those of all competitors, at home and abroad, soon put a stop to the importation of foreign types, instead of which the English types were now exported to several Continental States.

Composing.

(1077.) *Composing*.—All the types in use in the different printing-offices are sorted in cases or shallow boxes with divisions; there are two kinds of cases, the upper and the lower case, the latter lying nearest to the compositor upon the frame for their support. In the upper case are placed all the capitals, small capitals, accented letters, figures, and characters used as references to notes. In the lower case lie all the small letters, points, and spaces to place between the words. In the lower case no alphabetical arrangement is preserved, the letters having merely a larger or smaller box allotted to them, according as they are more or less frequently required, and all those letters most in request are placed at the nearest convenient distance to the compositor. By this ingenious but irregular division of the lower case much time in composing is saved, the operator requiring no label to direct him to the spot where the particular letter which he wants is to be found. To a stranger in a printing-office nothing appears more remarkable than the rapidity with which the compositor does his work, constant practice very soon leading the hand rapidly and mechanically to the letter required. When italic letters are to be introduced, they are taken from a separate pair of cases from the same fount.

The process of composing and forming types into pages has been slightly noticed in the alphabetical division of this Work; it is proposed here to explain it more particularly. Placing the copy or manuscript before him on the upper case, and standing in front of the lower case, the compositor holds in his left hand what is called the composing-stick. Sometimes this instrument is of wood, with a certain space cut in it of the particular width of a line or column; but more commonly it is made of iron or brass, with a movable side which, by means of a screw, may be regulated to any width of line. In either case the composing-stick is made perfectly true and square. One by one the compositor lifts and puts the letters of each word and sentence, and appropriate points, into his stick, securing each with the thumb of his left hand, and placing them side by side from left to right along the line. When he places a letter in the stick, he does not require to look whether he is placing it with the face in its proper position, this object being accomplished by looking at what is called the *nick*, which must be placed outwards in his composing-stick. This is one of those ingenious contrivances for saving labour which experience has introduced into every Art, and which are as valuable for diminishing the cost of production as the more elaborate inventions of machinery. When he arrives at the end of his line, the compositor has a task to perform in which the carefulness of the workman is greatly exhibited; for

it is requisite that the first letter and the last must be at the extremities of the line, as there must not be spaces left in some instances, and crowding in others, which would frequently occur without great care. Each metal type is of a constant thickness, so far as regards that particular letter, though all the letters are not of the same thickness, and the adjustments, therefore, to complete the line with a word, or at any rate with a syllable, must be made by varying the thickness of the spaces between each word. A good compositor is distinguished by uniformity of spacing; he will not allow the words to be very close together in some instances, and with a large gap between them in others, his duty being to equalize the spacing as much as he possibly can, which is in some cases very troublesome. In composing poetry, or similar matter, where there is always a blank space at one of the ends of the line, spacing is very easily accomplished by filling up the blank with larger spaces, or *quadrats*. Still, however, whether prose or poetry, the matter of each line must be equally adjusted and *justified*, so as to correspond in point of compactness with the previously set lines. The process of composing is greatly facilitated by the compositor using a thin slip of brass, called a *setting-rule*, which he places in the composing-stick when he begins, and which, on a line being completed, he pulls out and places upon the front of the line so completed, in order that the types he sets may not come in contact with the types behind them, and may smoothly glide into their places to the bottom of the composing-stick.

When the workman has set up as many lines as his composing-stick will conveniently hold, he places them on an elongated board, with a ledge on one or perhaps both sides, termed a *galley*, by grasping them with the fingers of each hand, and thus taking them up as if they were a solid piece of metal; and the facility with which some compositors can lift what is called a *handful* of movable type without deranging a single letter is very remarkable. This sort of skill can only be attained by practice; and one of the severest mortifications which the printer's apprentice has to endure is to toil for an hour in picking up about a thousand letters, and then to see the fabric destroyed by his own unskilfulness, leaving him to mourn over his heap of broken type, technically called *pie*.

Letter by letter, and word by word, is the composing-stick filled, and by the same progression the galley is filled by the contents of successive sticks. When the compositor has set up as many lines as fill a page, he binds them tightly round with cord, and removes them from the galley, and sometimes, as in the case of newspaper and similar work, the *handfuls* of type are accumulated till they fill the galley, and are then removed in long columns. After the matter is thus so far prepared, it is the duty of the compositor to take an impression or *first proof* from the types, and to correct the errors he may have made; these proofs are usually taken by means of an old large press kept for the purpose. This is not, however, always done, the proofs of galleys and pages being sometimes taken by a small iron roller, which runs on raised ledges upon a neat metal table, on which the types are placed, giving a sufficient impression to the compositor without any trouble. After the galley matter is corrected and recorrected by the compositor, it is divided into pages of the size wanted; and head-lines, or figures indicating their number, being added, the pages are arranged upon a large firm table, and there

Mechanical
Processes.

Manufac-
tures.

securely fixed up in an iron frame or *chess*, by means of slips of wood and wedges, or *quoins*.

This process, which is called *imposing*, being completed, and the face of the types being levelled by a *plainer* and mallet, the *form*, as it is called, is proved and prepared for press; proof-sheets are now taken, and subjected to the scrutiny both of a *reader*, employed in this peculiar function in the office, and of the author. These having made their marks pointing out words and letters to be altered or corrected, the compositor once more goes over the form, correcting the errors by lifting out the letters with a bodkin, and, when revised, the sheet is pronounced ready for working. It should be mentioned that the imposing table, at which all these corrections are made is composed of smooth stone or marble, on the top, from the circumstance of materials of that nature not being liable to rust from the water which is often thrown upon the types while preparing them for the press, or in laying them out for distribution after working off.

It is unnecessary to state that the size of books greatly varies; but the sizes are all reducible to a standard determined by the number of leaves into which a sheet of paper is folded. The most common size is *octavo*, each sheet of which contains eight leaves, or sixteen pages; the next is *duodecimo*, containing twelve leaves, or twenty-four pages in the sheet; and the next *octodecimo*, or eighteens, containing thirty-six pages in a sheet. There are many other sizes, such as the *quarto*, the smaller *twenty-fours*, &c. The knowledge of placing pages of types in a form so as to produce, when printed, a regular series upon paper, is one of the branches of the Art to be acquired by the young compositor.

Printing
presses.

(1078.) *Printing press*.—We come now to the description of the printing press, and the methods followed in the usual process of printing. The forms being duly composed in the composing-room are carried to the press-room, and are placed under the charge of the pressman.

The earliest printing presses were exceedingly rude, and seem to have resembled the common screw press, with a contrivance for running the form under the point of pressure, an operation which must have been laborious, slow, and exceedingly defective, from the difficulty of regulating the impression; it also endangered the face of the types. The defects in these original presses were at length remedied by an ingenious Dutch mechanic, Willem Jansen Blaew, who carried on the business of a mathematical instrument maker at Amsterdam; he contrived a press in which the carriage holding the form was run below the point of pressure, which pressure was given by moving a handle attached to a screw hanging in a beam having a spring, which caused the screw to fly back as soon as the impression was given. This species of press, which was almost entirely formed of wood, continued in general use in every Country in Europe till the beginning of the present century.

Common
printing
press.
Pl. lxxx.
Fig. 1.

The modern common press is represented in plate lxxx. fig. 1, in which A, A represent two cheeks or strong vertical iron sides, bound together by four horizontal bars; the first of these, B, is called the cap, and merely keeps the posts at a proper distance; the second cross bar C, called the *head*, is fitted by tenons at the ends into the mortises between the cheeks, and the bar admits of a small motion or play in consequence of the mortises being filled up with pieces of pasteboard or

soft wood; the head C is suspended from the cap B by two strong screw bolts *s, s*, and in the centre of it is fixed, by two short bolts, a brass nut, containing a female screw or worm for receiving the upper end of the great vertical spindle or screw S, by which the pressure is produced; the third bar D, called the *shelf* or *till*, is intended to guide and keep steady a part called the *hose*, which contains the spindle and screw; the next cross bar E, called the *winter*, is placed between the cheeks, in order to support the carriage, and it sustains the effort of the press below in the same manner as the head does above. The spindle or screw F F is a strong vertical bar of iron terminated at the lower end with steel; its upper end is formed into a small screw which works in the small brass nut of the head; and in the eye of the spindle, a little below its upper end, is fixed the crooked bar or handle H, by which the press is wrought.

Beneath the lower end of the spindle is placed the *plattin* G G, or the body which gives the pressure to the paper. It is suspended from the point of the spindle by the *hose*, a square frame or block of wood, shown at K, which is guided by passing through the shelves. The lower end of the spindle passes through the hose, and rests by its point in the plug, fixed in a brass pan supplied with oil, which is again fixed to an iron plate let into the top of the plattin; when the pressman, therefore, pulls the handle H he turns the spindle, the round of which moves in its screw box, and, descending, brings down the plattin, which thus presses upon the paper lying above the types. The plattin is suspended from the spindle and rises up again with it by means of a garter or fillet of iron screwed to the hose, and entering into a groove round the upper end of the spindle; the plattin is hung truly level by four threads passing from its four corners to the four corners of the lower part of the hose.

The next important part of the printing press is the *carriage* L L, the object of which is to bear the types and carry them below the plattin. The carriage is supported on a horizontal wooden frame, the fore part of which is sometimes sustained by a *forestay*, while the back part rests on the winter. Beneath the plank of the carriage, *cramp irons*, or short pieces of iron and steel, are nailed, which slide upon two long iron bars or ribs, fixed upon the upper part of the horizontal wooden frame. In order to run the carriage in and out upon the wooden frame, there is placed beneath the carriage the *split* or small spindle, having a double wheel on the middle of it, round which leather belts are fastened, the opposite end of the belt being nailed to each end of the plank of the carriage. On one of the ends of the split is fixed the winch or handle *n*, by turning which the pressman can run the carriage in and out below the plattin at his pleasure. The carriage consists of a strong wooden plank, on which is fixed a square wooden frame, forming the cell, in which a polished stone is placed to sustain the form or frame of types. Stay belts of leather are fixed to this cell by one end, and by the other to the cheeks of the press, so as to prevent the carriage from running out too far when drawn from under the platform. On the outer end of the plank is fixed the *gallows* M, which sustains the tympan when they are turned up to receive a new sheet of paper. These tympan, shown at N N, are light square frames covered with parchment. They consist of three slips of thin wood with a *headband* or top slip of thin iron. The two tympan are so constructed that the one is

Mechanical
Processes.

Manufac-
tures.

small enough to lie within the other, and the other and the exterior one is fitted by iron hinges to the cell; two or three folds of blankets are placed between the two tympana to equalize the pressure of the platin upon the surface of the types. A square frame of very thin iron, called the *frisket*, is fastened by hinges to the head-band of the exterior tympan. It is made to fall down upon the tympan, to enclose the sheet of paper between them, and the frisket is covered with a sheet of paper or parchment which is cut out so that the sheet when placed between the tympan and frisket and folded down together on the form of types may receive the ink from the surface of the types, while the frisket sheet preserves the margin from being soiled. When the tympan and frisket are thus folded down, they lie flat on the form of types, the carriage containing them is then run beneath the platin, so that, when the handle *H* is pulled, the platin presses upon one-half of the form of types; the carriage is then run further in beneath the platin to press upon the other half of the form of types. In this way the impression of the types is made upon the paper by two separate pulls; by turning the winch *n* the carriage is withdrawn from beneath the platin, and the tympan on being lifted up round its hinges rests obliquely against the galleys. The frisket is then lifted up on its hinges, and supported by a slip of wood descending from the ceiling till the printed sheet is taken out and a clean one put in.

Subsequent
forms of
press.

It has been already stated that scarcely any improvement, except in the neatness and firmness of the workmanship, was made in printing presses from a very early period of the invention to the commencement of the present century, about which time several new presses were proposed. Of these, the Apollo press, Prosser's press, Roworth's press, and the Stanhope press were the most important, particularly the latter. The impression by the common press being taken, as we have described, at two successive pulls, a part of the middle of each sheet receives two separate pressures, the effect of which is necessarily to diminish the uniformity of the impression on the paper, besides which, a great deal of time is wasted by having to give two separate pulls, so that it was very desirable to have such a change made in the old kind of press as to have the platin of sufficient size to effect the whole impression at once, or by a single pull only. The first invention of this kind was the Apollo press, imported into this Country from France. In this the platin was made of iron instead of wood, and its surface was large enough to print the whole sheet; the lower surface of the plate, which was of brass, was ground perfectly flat, and was of such thickness as not to bend nor yield at the parts most distant from the centre of pressure. The spindle was joined by connecting rods to a long lever placed by the side of the press, which was wrought by the pressman with both hands, in a vertical plane, like the handle of a pump; these presses, however, were worked only with great labour, and fell into disuse.

Apollo
press.

Roworth's press.—This is considered by some to have been the first really improved form of press after that described above as the common press. Here the spindle, instead of being furnished with a screw, is entirely plain, and has its upper extremity turned to a smooth cylinder, which works in a socket fitted into the head of the press; on the upper end of the spindle, immediately below the head, a short cross arm of hardened steel is fixed, the polished surface of which acts against a circular inclined

plane, also of polished and hardened steel, which, being actually a part of a screw, causes the spindle to descend. This inclined plane has different inclinations at different parts; at first the inclination is great, so that at the beginning of the pull the descent of the platin is rapid, but when it has approached near to the tympan, and, consequently, when the force is really required, the inclination of the plane is very slight, so as to produce the greatest mechanical effect.

Mechanical
Processes.

The next important improvement in printing presses was by the late Lord Stanhope, the machine being called after its inventor the Stanhope press; since which other forms have been proposed by Mr. Ruthven of Edinburgh; by Mr. George Clymer, called the Columbian press, being an American invention; Barclay's American press; Wells's press; and some others, which, however, we cannot undertake to describe in this article. We shall, therefore, refer only to the first two of these, viz.

(1079.) *The Stanhope press.*—This is represented in Stanhope pl. lxxx. fig. 2, 3, in which *A A* is the body of the press; this being a heavy cast-iron frame formed in one piece, which rests upon a wooden cross *B B C*, to which it is firmly screwed down. Two horizontal rails *D, D* are screwed, at *b, b*, fig. 3, to two projecting pieces cast all in one with the body of the press, in order to sustain the carriage when the pull is made. The ribs of the carriage are made to slide in grooves formed along the upper surface of these rails, and are moved by the handle *m*, with a split and leather belts resembling those in the common press. A brass nut or female screw is fixed in the upper part *d* of the body of the press, in which the upper end of the spindle works; the principal improvement of Lord Stanhope's press consists in his manner of giving the descending motion to the screw. The press is worked by a handle *H*, which is firmly fixed into the lower end of the vertical bar *M*, the lower point of which moves in a hole in the main frame, and the upper end passes at the same time through a collar in the projecting piece *c*; having passed through this collar, the end of the bar *M* joins a short lever *N*, which is again connected by the link *O* with another short lever *P*, fixed upon the upper end of the screw. The pressman, in pulling the handle *H*, turns round the spindle *M*, and, by its connection with the rod *O*, &c., the great lever turns with it and causes the platin to descend and produce the requisite pressure; the power of the lever *H* is, however, transmitted to the screw, in order to proportionate the effect required at the different parts of the pull. At the commencement of the pull, for instance, when motion only is wanted, the handle *H* lies in a direction parallel to the frame across the press, and the short lever *N*, which is nearly perpendicular to it, is likewise perpendicular to the connecting rod *O*; but the lever *P* of the screw makes a considerable angle with *O*, and it then acts by a spindle radius to turn the screw; when, therefore, the lever *H* begins to pull, the lever *N* acts with its full power upon another shorter length of lever on *P*, so that the screw will be turned more rapidly than if the link *O* were attached to it; the pull being continued, the situation of the lever changes, the length of *P* always increasing in its actual length from its coming nearer to a perpendicular to *O*, and the acting length of *N* diminishing, because by the obliquity of the lever the link approaches the centre. The handle *H* comes now into a more favourable position for the pull, as the

Stanhope
press.
Fig. 2, 3

Manufac-
tures.

pressman finally pulls in a direction nearly at right angles to its length; by this means the plattin is at first brought quickly down upon the paper where motion only is required; but as the levers are gradually coming into the most favourable position for exerting the greatest force, this maximum pressure is produced just at the moment when it is wanted, *viz.* when the plattin touches the paper to be printed. The range of the handle is limited by a stop, which is movable to a small extent, in order to vary the pressure for different kinds of work; the form of types, instead of resting upon a stone, lies upon a cast-iron block, which has its upper surface ground perfectly flat, and placed quite in a horizontal position. The size of the Stanhope press allows of a whole sheet being printed at one pull.

In some of these presses a variation of power is obtained by a screw adjustment at the end of the link O, as shown in the figure, by which it can be shortened. It is done by fitting the centre pin, which unites it to the lever P in a bearing place, and slides in a groove formed on the side regulated by the screw; thus the descent of the plattin may be increased or diminished, and its surface is turned so as to be perfectly plane. Since the invention of this press various improvements have been made upon it; one by M. de Heine has been secured by a Patent. In this the screw has been avoided by a spiral or curved inclined plane fixed on the head of the press. On the upper end of the spindle a cross arm is placed, which acts against a fixed inclined plane, and thus performs the functions of the screw; this substitute has its advantage by allowing the acting faces to be made of hardened steel. Mr. Peter Keir also made several valuable improvements on the Stanhope press: the slider *d* in this being formed by boring out a cylindrical hole down the centre of the press, and fits accurately into this cylinder, to the lower end of which is fastened the plattin; there is a flat side made to the cylinder, which is prevented from turning round by a bar of iron screwed across the two cheeks, and bearing against the flat side of the cylinder; the lever apparatus has likewise been improved by Mr. Keir. In the lower end of the spindle he has a screw cut and fitted into a nut; the spindle is made to rise and fall through a space equal to the descent of the great screw in the same time, and the connecting rod O is thus made to pull in a horizontal plane, while in the old construction one end remains level when the other descends, the consequence of which is an unequal wearing of the joints.

Ruthven's
press.
Pl. lxxx.
Fig. 4, 5.

(1080.) *Ruthven's printing press.*—This is represented in 4, 5, where A A is the tablet which sustains the form of types which remains fixed in the same position: this bed is supported by a framing of cast iron as shown in the figures; P P shows the plattin, and is joined to a strong cast-iron bar M M by screws *s, s*. At the ends of this bar there are strong iron bolts *b, b*, secured by screw nuts at the top; the bolts terminate below in heads or projecting pieces, which fit exactly the hooks or clutches at E, E; at each of the remotest ends of the bar M M is fixed an oval steel spring, and on the lower ends of each spring are two grooved wheels or rollers, which run on a railway, so that the whole plattin may be pushed off the form of types after it has given the pressure and again brought above M to press the succeeding sheet. These springs have their elasticity and form so adjusted that the lower surface of the plattin is raised above the margin of the tympan when the springs are not in action. The plattin, therefore,

readily moves into its position immediately above the tympan, and, as soon as it is pressed down upon the types, the action of the spring raises it above the margin of the tympan, and permits it to be pushed aside by the handle *h* from the form of types. We have already mentioned that the lower ends of the bolts *b, b*, which are generally shaped like the frustum of a wedge, go into a hollow of the same form when the plattin is pulled above the types; the object being to lock the plattin to the compound lever E F G H K L, which, when moved by the handle *h*, presses the plattin upon the types. This part of the apparatus consists of two levers, D F, D F, moving upon fixed centres at D, D; the clutches, of wedged-shaped cavities, are joined to these levers near the fulcra D, D, so that when the extremities F, F of the levers D F, D F are pulled down, the clutches are also pulled down, and therefore bring down the plattin to which they are locked. The descent of the ends F, F is produced by a link G united to both, and this link is again joined to another lever whose fulcrum is at K, while the other end is connected with the handle *h*, by which the pressure is given. These levers are so arranged that the maximum force is given when the plattin just begins to touch the tympan. The plattin in Mr. Ruthven's large presses is the size of a full sheet, and, in consequence of the pressure not being propagated from its centre, the pressure over the whole sheet becomes more equable than in other presses.

(1081.) *Printing machines.*—Notwithstanding all the ingenuity which had been exercised in improving the printing press, its powers, as we have already observed, were inadequate to the demand created by the general spread of education and spirit of inquiry amongst the English people. After all the improvements, a single press could only work off at an ordinary rate about 250 impressions or 125 sheets per hour; and although, by excessive labour, a greater number were produced in our newspaper printing-offices, yet it was necessary to have duplicate presses and set up forms of type to carry on such work, and still the production of copies was quite inadequate, in point of time, for our increased rapidity of transfer from the metropolis to the distant parts of the Country. Hence the absolute necessity for some great change in the Art of printing; and the first attempt was, we believe, made in 1790 by the late ingenious Mr. William Nicholson, who procured a Patent for his invention, which embodied, in point of principle, much of what has since been effected.

Mechanical
Processes.

Printing
machines,
invention
of.

First Pa-
tent by Mr.
Nicholson.

It is uncertain whether or not Mr. Nicholson's views were known to Mr. König, a German, but to the latter is, at all events, due the honour of having first carried steam printing into effect.*

Mr. König, conceiving it possible to apply steam-power to produce accelerated speed with the common press, after various unavailing efforts to obtain assistance from the printers on the Continent, came to England, and arriving in London about 1804, he submitted his scheme to several printers there with no better success, until he was introduced to Mr. Bensley, senior, who, attracted by Mr. König's plans, entered into arrangements with him. After persevering for some

König's
Patent.

* Mr. König having claimed the invention of *cylindrical* printing, Mr. Cowper once asked him if he was aware of what Nicholson had done, and Mr. König said, "He had made a point of not reading any thing that other persons had done, in order that the machine might be entirely his own invention."

Manufac-
tures.

time in various attempts to accelerate the speed of the common press, and at the same time to render the attendance of the man who inks the types unnecessary, his exertions resulted, to use his own words, "in discovering that they were only employing a horse to do what had been before done by a man." He in consequence gave up all idea of his projected improvements of the common press, and turned his attention to cylinder printing.

After continued experiments for some years, a small machine was made, in which the leading features of Nicholson's invention were embraced, which he exhibited to Mr. Walter, proprietor of the *Times* newspaper; and, on showing what further improvements were contemplated, an agreement was entered into for the erection of two machines for printing that journal. Accordingly, on the 28th of November, 1814, the public were apprized that the number of the *Times* of that date was the first ever printed by machinery, steam propelled. Mr. König subsequently made a machine to print both sides of the sheet before leaving the machine. Both these machines were extremely ingenious, but the inking apparatus, containing forty wheels, was very complicated, and sometimes occupied two hours to get it into working order.

Applegath
and Cow-
per's Pa-
tent.

Notwithstanding the ingenuity displayed in the construction of this machine, it was soon superseded by that of Messrs. Applegath and Cowper, who, in the year 1818, took out a Patent for performing the operation of steam printing; the main principle of which, as characteristic of the invention, consisted of the application of two drums placed between the cylinders to ensure accuracy in the register, over and under which the sheet was conveyed in its progress from one cylinder to the other, and in the mode of distributing the ink upon the tables instead of rollers; two principles which have secured to machines of this construction a decided preference for fine works. Machines of this construction have been made by Messrs. Applegath and Cowper for the principal printing establishments in London, Paris, Edinburgh, and other Cities.

Present
variety of
printing
machines.

Printing machines are now made of various kinds, adapted to the peculiar descriptions of work for which they are required. These descriptions of work may be classed under two distinct heads, namely, the printing of newspapers one side at a time, and the printing of a better kind of sheets, or book-work, both sides at a time. There can be nothing more easy than to make a machine capable of first printing one side of a sheet of paper, and afterwards the second, by the removal of one form and the introduction of another; but this process will not produce *register*: the second side may or may not be on the back of the first, and the work is therefore of a very inferior appearance, though suitable enough for newspapers, in the working of which despatch is alone required. This kind of press is therefore the best adapted to gain that end; for the first side of the paper may be printed deliberately, and the second side be made up to the last moment of time, and then thrown off. To produce a machine to print both sides at a time, and with perfect register, no small degree of mathematical accuracy, and no small share of ingenuity in the mechanician, are required. The great and important object to be attained in this kind of machine is to cause the sheet, after it has received its first impression, to travel along the sides of the cylinders and drums at such a rate as to meet the types of the second side at the exact point which will cause the second side to fall with

Mechanical
Processes.

perfect accuracy upon the back of the first. To accomplish this exceedingly desirable end, the cylinders and drums must revolve at precisely the same speed as the carriage underneath; and therefore any inaccuracy in the turning of the axles, the cutting of the teeth of the wheels, or any other deficiency, however slight, will produce badly registered sheets, and create an enormous degree of vexation to the printer. It is of equal importance that the ink should be perfectly "distributed," and that the face of the type should be perfectly covered without being *smothered* with ink, and that the whole of the inking apparatus should be under complete control, and easily put into working order.

The first persons who succeeded in these great desiderata were the Patentees last mentioned; for although, as we have seen, Mr. König was the first person who brought the printing machine actually into operation, the invention was still far from being completed, much still remaining to be effected. It is therefore to Messrs. Applegath and Cowper we must consider ourselves indebted for the astonishing perfection to which these machines have now arrived, as will appear more fully from the following description of two of their machines, in the course of which some historical facts are referred to which have been hitherto much misrepresented.

Applegath and Cowper's Printing Machine.

(1082.) This machine, represented in fig. 1, plate lxxxi., is adapted to print both sides of the sheet of paper before it leaves the machine, and it prints from 800 to 1000 sheets per hour on both sides, the common press printing only 125 sheets on both sides in the hour.

Applegath
and Cow-
per's print-
ing ma-
chine.
Pl. lxxxi.
Fig. 1, 2.

The supply of blank paper is laid on a table A, whence the sheets are taken one by one by a boy standing on an elevated platform who lays them out on the feeder B, which has a number of linen girths passing across its surface and extending round a roller at each end of the feeder, so that, when the rollers are partially turned round, the motion of the girth carries the sheet forward and delivers it over the entering-drum E, where it is seized between two systems of endless tapes passing over a series of rollers to keep them extended. These endless tapes are so adapted in number and position as to fall between the pages of the printing, and also on the outsides of the printing, *i. e.* the edges of the sheet; they may therefore remain in contact with the sheet of paper on both sides during its whole passage through the machine, by which means the paper is conveyed from the printing cylinder F to the other printing cylinder G without destroying the "register," *i. e.* the coincidence of the pages on the opposite side of the sheet. F and G are the printing cylinders, which are made of iron and turned perfectly true, and are clothed with fine woollen cloth, technically called *blanket*, in those parts where the sheet falls to receive the impression; they are mounted on strong axes which turn in bearings affixed to the main frame of the machine. The bearings are adjustable by screws to every degree of pressure. H and I are the conveying drums; they are made of wood, and convey the sheet steadily from one printing cylinder to the other.

The manner in which the endless tapes (before mentioned) are arranged is as follows. We will suppose one system of tapes to commence at the upper part of the entering-drum E; thence they proceed in contact with the right-hand side and under portion of the printing

Manufac-
tures.

cylinder F; they then pass *over* the conveying drum H and *under* the conveying drum I, whence they proceed to encompass the left-hand side and under portion of the printing cylinder G, and, by passing in contact with the small rollers *a, b, c, d*, they arrive again at the roller E, whence they commenced, thereby forming one of the systems of endless tapes; the other system we will suppose to commence at the roller *h*. They are equal in their number to the tapes already described, and correspond with them also in their places on the cylinders, so that the sheets of paper may be held securely between them. These second tapes descend from the roller *h* to the entering-drum E, where they meet and coincide with the first system in such a manner that the tapes proceed together *under* the printing cylinder F, *over* H, *under* I, and round G, until they arrive at the roller *i*, when they separate, having remained thus far in actual contact, except at the places where the sheets of paper are held between them. From the roller *i* the tapes descend to a roller at *k*, and by passing in contact with rollers at *l, m, n*, they arrive at the roller *h*, from whence they commenced; thus the two systems of tapes act continually in concert without interfering with each other. See diagram, fig. 1. The cylinders and drums are all connected by toothed wheels, so as to insure a uniform and steady motion.

The two separate forms of type are placed at a certain distance from each other on a long carriage, and an inking table, *i. e.* an extended metal surface, is also placed on the carriage and close to each form. The carriage, with the two forms of type and the two inking tables, moves backwards and forwards from one end of the machine to the other on rollers attached to the main frame of the machine, and in its journey bringing the types in contact with the sheet of paper on the circumference of the printing cylinders. This reciprocating movement is produced by a pinion working into the alternate sides of a rack under the tables, motion being given to the pinion by the bevel wheels K. The mechanism for furnishing the proper quantity of ink for *distributing*, *i. e.* equally spreading it over the inking table and finally applying it to the types, performs its operations with great delicacy and certainty. This is a very important part of the machine, a single *grain* of ink being frequently sufficient for one side of a sheet.

Two similar and complete sets of inking apparatus, one at each end of the machine, are adapted to ink their respective forms of type; we will therefore describe one, a metal roller L, called the ductor roller, which has a slow rotary motion communicated to it by a catgut band passing round a small pulley upon the end of the axis of the printing cylinder G. A horizontal plate of metal, the edge of which is ground straight, is adjusted by screws so as to be almost in contact with the ductor roller; a back is put to the horizontal plate, so that the whole forms a sort of trough in which the mass of ink is placed, and as the metal roller revolves it becomes covered with a thin film of ink. An elastic composition roller, called the vibrating roller, is made to vibrate between the ductor roller and the inking table; when the vibrating roller rises, it touches the ductor roller and takes a small portion of ink, and when it descends, it deposits the ink on the inking table. Three or four rollers of small diameter, called distributing rollers, are placed across the machine at M. They are not placed *directly* across, but in a somewhat diagonal direction, being about two inches out of the perpendicular; the spindles

of the distributing rollers are made long, and they lie in notches and not in fixed bearings. As the table moves under them, they not only rotate but also have an end-motion, *i. e.* a motion in the direction of their length, in consequence of their diagonal position, and this compound motion obliterates all inequalities and produces a perfect *distribution* of the ink on the inking table; the inking table then passes under the three or four inking rollers N, to which it conveys the distributed ink, and they, in their turn, ink the type; thus each time the type passes to and fro, *i. e.* for every sheet printed, the form is touched no less than eight times by the inking rollers. The distributing rollers and the inking rollers all turn in notched bearings, leaving them at liberty to move up and down, in order that they may bear with their *weight* on the inking table and the form; they therefore require no adjustment by screws, but are ready for work by merely being dropped in their notched bearings.

The machine is put in motion by a strap from a steam-engine to a rigger at the back of the machine, or by a fly-wheel turned by hand; they require but little power to turn them. Messrs. Clowes of Stamford-street have twenty of Applegath and Cowper's machines worked by two five-horse engines.

The operation of printing is performed as follows. The sheets of blank paper are laid one by one on the feeder B on the linen girths; the rollers C and D are now caused to move a portion of a revolution (by means of a segmental wheel.) This motion advances the sheet of paper sufficiently to enable it to enter between the two systems of endless tapes at the point where they meet each other on the entering-drum E. As soon as the sheet is fairly between the tapes, the rollers C and D are, by the operation of a weight, drawn back to their original position ready to advance another sheet into the machine. As the sheet is carried along between the endless tapes, it applies itself to the blanket on the printing cylinder F, and as it revolves it meets the first form of types and receives the impression from them; the sheet now printed on one side is carried over H and under I to the blanket on the printing cylinder G, at which place it will be found in an inverted position, the printed side being in contact with the blanket and the blank side outward, which, upon meeting the second form of types at the proper instant, receives the second impression and completes the sheet. On arriving at the point *i*, where the two systems of tapes separate, the perfect sheet is thrown out into the hands of a boy. An engraving and description of this machine appeared in the *Literary Gazette*, October 26, 1832, where it is called "Bensley's machine." This is a mistake, as Applegath and Cowper are the inventors, patentees, and actual makers of the identical machine from which the engraving was made. It is, therefore, only in the sense of his having *purchased* that machine of the Patentees that it could be called "Bensley's machine." The mistake, however, has been perpetuated by the *Encyclopædia Britannica*, and by Hansard's *Typographia*, both of which have copied the engraving, with its erroneous title and description.

These are the machines which are now in general use, all the large publications of the present day being printed by them, the *Encyclopædia Metropolitana* among the number; indeed, without them, such Works as the *Penny Magazine*, the *Saturday Magazine*, *Chambers's Journal*, and the *Magazin Pittoresque* and *Magazin Universel*, of Paris, could not exist. Of these

Mechanical
Processes.

Manufactures. useful Works upwards of 350,000 copies are printed every week by Applegath and Cowper's machines.

Inking table. (1083.) *Inking table.*—The success which attended the system of inking in the printing machine induced Messrs. Applegath and Cowper to apply the same principle to the common press. A representation of this contrivance is shown in fig. 1, plate lxxxii. It consists of an ink trough composed of a straight edge and ductor roller as in the machine above described, and an inking table and hand-inking roller; the ductor roller being turned round by hand becomes covered with a film of ink, the hand roller, mounted on a spindle and furnished with handles, is dabbed against the ductor roller, and then rolled backward and forward on the table, and then rolled over the type: this invention has formed an era in the Art of printing, for it has raised the quality of printing all over the world. Work, such as the first editions of the *Encyclopædia Britannica* and Rees's *Cyclopædia*, which in those days was considered good, would now not be tolerated for a newspaper or a tract.

Mr. Donkin is the inventor of the elastic composition roller, but he only introduced it in an unsuccessful machine, and never applied it to the common press.

In Hansard's *Typographia*, p. 630, this invention of the hand-inking apparatus, Mr. H. suggests, may be the simultaneous invention of Mr. Forster and Mr. Harrild, declaring it very difficult for him to assign the palm of priority to either. This difficulty arose from the simple fact that it was the invention of neither, but was the invention and Patent of Mr. Cowper, and both Mr. Forster and Mr. Harrild were merely *agents* appointed by Messrs. Applegath and Cowper for the sale of the apparatus.

The small diagrams in plate lxxxii. will give a general idea of the varieties of inking apparatus and arrangement of machines, and is in fact an epitome of the history of printing machines. Fig. 2 is Nicholson's machine for arched type; fig. 3 is Nicholson's for common type; fig. 4 is König's machine for one side of the sheet; fig. 5 is König's for both sides; fig. 6 is Donkin and Bacon's for one side; fig. 7 is Cowper's for curved stereotype and one side of the sheet; fig. 8 is Cowper's for curved stereotype and both sides of the sheet; fig. 9 is Applegath and Cowper's for one side and for common type; and fig. 10 is Applegath and Cowper's for both sides of the sheet, *i. e.* the machine above described.

(1084.) *Applegath and Cowper's Newspaper Machine at the Times' Office.*

As one side of a daily paper contains advertisements and matter of little importance, one side is generally printed sometime before the second side, which contains the debates in Parliament and the latest news; the great object, therefore, in a newspaper like the *Times* is to obtain as many impressions as possible from *one* form.

This was accomplished by making the form pass under *four* printing cylinders, the cylinders being made to rise and fall, in order to use cylinders of small diameter and thus bring them near to each other, and consequently shorten the journey of the form to and fro as much as possible. As two men cannot stand at the same feeders at the same time, two additional feeders were placed as it were on an *upper floor*, in order to supply the cylinders with paper.

Fig. 2, plate lxxxii., is a diagram of the machine invented by Applegath and Cowper for the *Times* newspaper.

In this machine there are four places to lay on the sheets and four to take off, consequently eight lads are employed to attend the machine. P, P, P, P are the four heaps of paper; F, F, F, F the four feeding boards; E, E, E, E the entering-drums on which the sheets enter the tapes *t, t, t, t*, whence they are conveyed to 1, 2, 3, 4, the printing cylinders; T the form of type; I I two inking tables, one being placed at each end of the form. The inking apparatus is similar to that in the machine already described, with the addition of two central inking rollers R, R, which also receive their ink from the inking tables. The printing cylinders 1, 2, 3, 4 are made to rise and fall about half an inch, the first and third at the same time, and the second and fourth at the same time. As the form of type passes from A to B it prints sheets at 1 and 3, and as it returns from B to A it prints sheets at 4 and 2; the cylinder alternately falling to give the impression, and rising to allow the form to pass.

Each of the lines marked *t* consists of two endless tapes running in contact in the parts shown, but separating at the entering-drums E, and at the taking off part o, o, o, o, the *return* of the tapes to the entering-drum being omitted to avoid confusion.

Operation of the machine.—The sheets being laid on their respective feeding boards with the fore edge just lying on the entering-drum, at proper intervals, a small roller, called the drop-down-roller, drops down on the edge of the sheet; the drum and the roller being in motion the sheet is instantly carried forward, between the tapes *t*, down to the printing cylinder, and thence upwards to o, o, o, o, where the tapes separate and the sheet falls into the hands of the boy.

The machine is under such complete management, that it is generally in full work within four minutes after the form is brought into the machine room.

The speed of König's machine by which the *Times* was formerly printed was 1800 per hour. The speed of Applegath and Cowper's machine is 4200 per hour, and it has been in daily use for more than six years.

Copper-plate Printing.

(1085.) This relates to working off engravings from copper, or other metal plates, and, in point of antiquity, is nearly of the same age with the Art of printing with movable types, having been first practised during the XVth Century. The subject of engraving, considered as one of the Fine Arts, has been already examined at considerable length under that division of this Work. Our only business here, therefore, is with the mechanical parts of the process, of which printing is the principal; but to prevent unnecessary reference, we shall say so much on the more common description of engraving as may be required for the purpose of those who look only to the mechanism of the process; those who wish for more minute information must consult the article referred to.

(1086.) *Engraving with strokes* is undoubtedly the most ancient, and, although a slower process than the other species of engravings, is still practised where extreme delicacy is required. Here the copper-plate intended to be engraved should be perfectly polished, very level, and free from every imperfection; to this must now be transferred an exact copy of the outlines of the drawing. To do this the plate is heated in an oven or other-

Mechanical Processes.

Pl. lxxxii
Fig. 2.

Copper-plate.
Printing.

Engraving
with
strokes.

Manufac-
tures.

wise very uniformly till it is sufficiently hot to melt white wax, a piece of which is then rubbed over it and allowed to spread so as to form a thin coat over the whole surface, after which it is left in a horizontal position till the wax and plate are cold. A tracing being taken of the original design with a black-lead pencil on a piece of thin tracing paper, this is spread over the face of the prepared plate with the lead lines downwards, and, being secured from slipping, a strong pressure is made use of by a press or otherwise, by which operation the lead lines are nearly obliterated on the paper, being transferred to the white wax on the plate. These pencil marks on the wax are now traced with a fine steel point, so as just to touch the copper; the wax being then melted off, a perfect outline will be found on the copper, and on this the engraver proceeds to execute and finish his work.

The implements used for the purpose are *gravers* of various forms, a *scraper* for removing the burs which naturally follow the graver, a *burnish stone*, *oil stone*, *oil rubber*, *rullers*, *compasses*, *parallel*, *charcoal*, &c. With respect to the process itself it would be useless to speak; it depends on a manual dexterity and genius which it is impossible to teach by description.

Etching.

(1087.) *Etching*.—Here the plate, instead of being covered with white wax, is coated with a composition of a resinous description which dries harder than the wax, and at the same time resists the action of the acid afterwards to be employed. A copy of the drawing is transmitted to the thin coating on the plate in a manner similar to that above described; this is now traced over with a fine steel point, whereby the composition is removed from those parts and the copper exposed; a wall or border is then formed round the edge of the plate of a composition of wax softened by Burgundy pitch or tallow, and the plate being laid flat a quantity of dilute nitric acid is poured on to the depth of about half an inch; this immediately acts upon the parts of the copper laid bare by the tracing, and bubbles, proceeding from the decomposition of the metal, &c., will rise, which must be carefully removed with a feather as fast as they appear, and also all such as are observed to adhere in the strokes. When the subject to be engraved is a mere outline or very plain figure, the acid, being left to act for a greater or less time according to circumstances, is poured off, and the composition being also removed, it will be found that all the lines previously traced on the composition are now transferred to the copper-plate, but commonly requiring to be finished off with the graver.

In more delicate designs, however, this simple process is not sufficient; parts of the drawing are lighter than others, and on the plate the lines must be less deep; in these cases the process is as follows. When the faintest parts of the design are supposed to be sufficiently bitten the nitric acid is poured off and the plate washed with water, leaving of course the composition on. These light parts are then covered with what is called a stopping mixture, to prevent the further action of the acid on those parts, the acid is then again poured on, and the same operation repeated as often as is necessary to produce all the different degrees of strength in the different parts. The plate is then heated and some olive oil poured on to facilitate the removal of the composition, which being effected, the engraver proceeds to complete the work thus commenced by the acid with the graver, scraper, burnisher, &c., as already described in the former mode of engraving.

It may be observed that etching, in its original sense,

was supposed to imply the simple process of etching without the aid of the graver, but it is very seldom that such is the case; so also in original engraving, the graver is supposed to be employed independently of acid; but in the present state of the Art professed etchings are seldom made without some finish from the graver, and few engravings without the previous assistance of acids.

(1088.) *Mezzotinto engraving*.—Here the plate is prepared by polishing, &c., as for other kinds of engraving, and is afterwards divided equally by lines parallel to each other which are traced out with very soft chalk. The distance of these lines should be about one-third of the length of the face of the grounding tool which is to be used, and they should also be marked by letters or otherwise to distinguish them from each other. The grounding tool is then placed between the two first lines and passed forward in the same direction with them; it must be held as steadily as possible and pressed upon with a moderate force, rocking it from end to end till it has completely hacked all the parts of the plate between those two lines; the same operation must be repeated with respect to all the other lines till the tool has passed over the whole surface of the plate and rendered it uniformly rough throughout. Other lines must then be drawn across the plate at right angles to these, and the operation above described repeated. Similar lines are now drawn diagonally, and these again are crossed at right angles to themselves with other lines, the grounding tool being still used the same in all: this forms what is called the first order of lines. These are now followed by the second order, which have the same breadth as the first, but they are laid on so as to divide those already made into spaces one-third less than their original width. Then follows the third order of lines, at the conclusion of which the plate is said to have had one turn; but to produce a very uniform dark ground these several operations require to be repeated several, perhaps twenty, times.

This process being at length completed, the sketch of the design or outline must be chalked on it by rubbing the back of the paper or drawing with chalk, and tracing the outline with a pointer, as in etching. It is also proper to overtrace it afterwards with black lead or Indian ink, in order to produce a more distinct and permanent sketch. The operation of the engraver now commences by his scraping away the grain of the ground in various degrees, so that none of it is left in its original state except in the touches of the strongest shades, the general method of proceeding being similar to that of drawing with white upon black paper. The masses of the strongest lights are first begun and scraped pretty smooth, and some parts, where there is no shade, are burnished, and those parts which go off into the light in the upper part but are brown below. The next lower gradations of shade are then scraped down, after which the reflected lights are entered upon. The plate is next blackened with a printer's ball made of felt, in order to discover the effect; the work is then proceeded with again, again examined, and so on till the desired effect is produced.

(1089.) *Aquatinta*.—This is a method of producing prints very much resembling drawings in ink. The principle of the process consists in corroding the copper with aquafortis in such a manner that an impression from it has the appearance of a tint laid on the paper. This is effected by covering the copper with a powder of some substance that will take a granulated form, so as to

Mechanical
Processes.

Mezzotinto
engraving.

Aquatinta
engraving

Manufac-
tures.

prevent the acid from acting where the particles adhere, and by this means corroding the copper partially, and in the interstices only. When these particles are extremely minute and near to each other the impression from the plate appears to the naked eye exactly like a wash of Indian ink, but when they are larger the granulation is more distinct; and, as this may be varied at pleasure, it is capable of being adapted with success to a variety of subjects.

The substances which have been mostly used for this purpose, either separately or mixed, are asphaltum, Burgundy pitch, resin, gum copal, and gum mastic; and in a greater or less degree all resins and gum resins will answer the purpose. Common rosin is most generally used and has been found to answer very well, though gum copal makes a grain that resists the aquafortis better. The substance intended to be used for the grain must be distributed over the plate as equally as possible, and different methods of performing this essential part of the operation have been used by different engravers, and at different times. The most usual way is to tie up some of the powder in a piece of muslin and to strike it against a piece of stick held at a considerable height above the plate; by this means the powder that issues falls gently and settles equally over the plate. The plate being thus covered over with the dust or powder, the operator is next to proceed to fix it upon the plate by heating the latter gently so as to melt the particles. This may be effected by holding lighted pieces of paper under it and moving them about till all the particles are melted, which will be indicated by its change of colour. The plate is now left to cool, when it may be examined with a magnifier, and if the grains or particles appear to be uniformly distributed, it is ready for the next part of the process. The design or drawing to be engraved must first be examined, and such parts of it as are perfectly white are to be re-marked, and the corresponding parts of the plate must be covered or stopped out with turpentine varnish diluted with turpentine to a proper consistence to work freely with the pencil, and mixed with lamp-black to give it colour, for, if transparent, the touches of the pencil would not be so distinctly seen; the margin of the plate must also be covered with varnish, and when the stopping out is sufficiently dry a border of wax must be raised round the plate in the same manner as described under etching, and the acid, properly diluted with water, poured on. This part of the process, called the biting in, is the most uncertain, and requires skill and experience.

When the acid has remained on a sufficient time to produce the lightest shade in the drawing, it is poured off, and the plate washed with water and dried; the lightest parts being now stopped out as described in etching, the acid is again poured on, and the process repeated as often as necessary. Many plates are etched entirely by this method of stopping out and biting in alternately, yet it may be easily conceived that, in general, it will be difficult to stop round and leave out all the finishing touches, as also the leaves of trees and many other objects.

To avoid these difficulties, another process is sometimes had recourse to by which these touches are laid on the plate with the same ease and expedition as they are on a drawing of Indian ink. Fine washed whiting is mixed with a little treacle or sugar and diluted with water in the pencil so as to work freely, and this is laid on the plate covered with the aquatint ground in the

VOL. VIII.

same manner and on the same parts as the ink on the drawing. When this is dry, the whole plate is varnished over with a weak and thin varnish of turpentine, asphaltum, or mastic, and then left to dry; the aquafortis is then poured on. The varnish now breaks up in the parts where the treacle mixture was laid, and thereby exposes all those places to the action of the acid while the rest of the plate remains secure. The effect of this is that all the touches or places where the treacle was used will be bit in deeper than the rest, and will have all the precision and firmness of touches of Indian ink.

After the plate is completely bitten in, the bordering of wax is taken off by heating the plate, as already described under etching; it is then cleared from the ground and varnished by oil of turpentine, and wiped clean with a rag and a little fine whiting, when it is ready for the printer.

Other means are sometimes employed, but perhaps sufficient has been said on a subject which is scarcely a part of our general design.

(1090.) *Engraving in chalk.*—This is a species of Chalk engraving. engraving. intended to imitate drawing in chalk, and is capable of great effect. It is a kind of etching by dots, the principal difference between it and the usual etching being, that the several shades, &c., in the work are produced by dots instead of strokes. The plate is prepared and the ground laid exactly as described, (Art. 1089.) and the drawing traced also in like manner. The outline of the drawing must now be formed by etching in points which will form dots whose size and distance must depend upon the strokes in the original drawing. In forming the lights and shades, it is necessary to distinguish those hatches which serve to express the perspective of the object from those which form the ground. The latter are marked strongly, the middle tints lightly, and the weaker are last reserved to be performed dry with the graver. The acid being applied as described under etching, when the lighter shades are sufficiently bitten in the acid must be poured off, and those parts stopped with turpentine varnish. The acid is then again poured on and left to act till the next deeper shades are produced, and so on, as in etching. The ground is now removed, and the finer dots introduced with the graver as above stated.

The principal object of this kind of engraving is to imitate drawings in chalk. The stroke of the chalk in the drawing is a succession of small dots where the chalk passes over the asperities or eminences on the surface of the paper, and it is these irregular dots which are produced with this kind of etching. In many cases the imitation is exceedingly close, so that an artist is sometimes almost unable to distinguish between the copy and the original. Drawing in different-coloured chalk may be imitated by this kind of engraving if a plate be made for every colour, which of course is laid on one after the other in the printing. The French have very well imitated drawings on blue paper by using two plates, from one of which the black chalk effect is produced, and from the other the effect of the white chalk. Chalk plates, likewise printed on black or blue paper, may afterwards be touched with white chalk, thereby producing a very good effect.

(1091.) *Engraving on steel.*—Some of the earliest Engraving on steel. engravers, particularly Albert Durer, used steel plates for engraving, but they were afterwards wholly rejected for those of copper. Within a few years, however, the arts of decarbonizing and recarbonizing steel have been carried to a great perfection, and engraving on steel is now very commonly executed for works which call for a great

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Manufac-
tares.

number of impressions, the steel plate allowing many more copies to be taken than the copper one before it is deteriorated. The method of engraving is the same as copper-plate engraving, except in certain modifications in the use of the acids, and therefore, so far as the process is concerned, no particular description is necessary; but it will be proper to explain the means employed for decarbonizing the steel plate so as to reduce it to a proper state for being acted upon by the graving tool. Mr. C. Warren, an eminent English artist, has the merit of having re-established engraving on steel; he communicated his process to the Society of Arts in 1823, who awarded him their gold medal for his invention, but he unfortunately died before it was ready for delivery. An account of his process for decarbonizing the plate is given in the Society's *Transactions*, vol. xli. This has been since improved; and, as we shall describe the method employed by Messrs. Perkin, Heath, and Co., in a subsequent article, it will be sufficient to refer the reader, who is desirous of studying Mr. Warren's method, to the Work quoted above.

Method of
preventing
forgery of
bank-notes.

(1092.) *Engraving for preventing forgery.*—Another beautiful application of engraving on steel was introduced, about the same time as Mr. Warren's communication, by Mr. Perkin, an American engineer, who, with Messrs. Heath and Fairman, obtained a Patent for the invention; this was intended principally to prevent the forgery of bank-notes, which at that time, or rather previously to that time, had been carried on to a very fearful extent. According to this plan a steel plate, decarbonized as described below, is engraved or etched in the usual way; it is then recarbonized and rendered very hard. A cylinder of very soft or decarbonized steel is now made to roll under a great pressure backward and forward on the hardened engraved plate till the entire impression from the engraving is seen on the cylinder in alto-relievo. The cylinder is then hardened and made to roll again backward and forward on a copper or soft steel plate, whereby a perfect fac-simile of the original is produced of equal sharpness.

This ingenious process was to be applied for the prevention of forgery in the following manner. It was proposed in this way to produce a beautifully-executed design on a small scale by employing a first-rate artist, and to repeat its impression on the face of the note as often as might be thought desirable, every one of which would be so exactly alike that no magnifying power would be able to distinguish any difference; an accuracy of copy which it was supposed it would be impossible to imitate if engraved successively on the plate by the most able artists. To increase the difficulty of imitation, it was also proposed to employ several artists of the first rank to produce each a specimen, and to introduce them all on the same plate, which would of course increase the difficulty and expense of the plate; at the same time it was stated that, notwithstanding this great first cost, the entire expense to the Bank of England, after a very short time, in consequence of their extensive issue, would be lessened, the steel plates thus hardened lasting a much longer time serviceable than the copper plate would do. The change, however, which took place in the currency about the time this proposition was made caused it to be neglected, and we believe that at present it is but little practised. The method employed for decarbonizing and recarbonizing the plate, however, may be applicable to many other useful purposes, and we shall therefore give it in the words of the Patentees. "In order to decar-

bonate the surfaces of cast-steel plates, cylinders, or dies, by which they are rendered much softer and fitter for receiving either transferred or engraved designs, we use pure iron filings divested of all foreign or extraneous matters. The stratum of decarbonated steel should not be too thick for transferring fine and delicate engravings, for instance, not more than three times the depth of the engraving; but for other purposes the surface of the steel may be decarbonated to any required thickness. To decarbonate it to a proper thickness for a fine engraving, it is to be exposed for four hours in a white heat, enclosed in a cast-iron box with a well-closed lid. The sides of the cast-iron box are made at least three-quarters of an inch in thickness, and at least a thickness of half an inch of pure iron filings should cover or surround the cast-steel surface to be decarbonated. The box is allowed to cool very slowly, which may be effected by shutting off all access of air to the furnace, and covering it with a layer of six or seven inches in thickness of fine cinders. Each side of the steel plate, cylinder, or die, must be equally decarbonated, to prevent it from springing or warping in hardening. It is also found that the safest way to heat the plates, cylinders, or dies, is by placing them in a vertical position. The best steel is preferred to any other sort of steel for the purpose of making plates, cylinders, circular or other dies, and more especially when such plates, cylinders, or dies, are intended to be decarbonated. For the reason given above, the steel is decarbonated solely for the purpose of rendering it sufficiently soft for receiving any impression intended to be made thereon; it is therefore necessary that, after any piece of steel has been so decarbonated, whether it be in the shape of a plate, or a cylinder, or a die, it should, previously to being printed from, be again carbonated or reconverted into steel capable of being hardened. In order, therefore, to effect this decarbonization or re-conversion into steel, the following process is employed: a suitable quantity of leather is to be converted into charcoal by the well-known method of exposing it to a red heat in an iron retort for a sufficient length of time, or until most of the evaporable matter is driven off the leather. Having thus prepared the charcoal, it is reduced to a very fine powder; then take a box made of cast iron, of sufficient dimensions to receive the plate, cylinder, or die, which is to be reconverted into steel, so as that the intermediate space between the sides of the said box and the plate, cylinder, or die, may be about an inch. This box is to be filled with the powdered charcoal, and, having covered it with a well-fitted lid, let it be placed in a furnace similar to those used for melting brass, when the heat must be gradually increased until the box is somewhat above a red heat; it must be allowed to remain in that state till all the evaporable matter is driven off from the charcoal; then remove the lid from the box, and immerse the plate, cylinder, or die, into the powdered charcoal, taking care to place it as nearly in the middle as possible, so that it may be surrounded on all sides by a stratum of the powder of nearly an uniform thickness. The lid being replaced, the box, with the plate, cylinder, or die, must remain in the degree of heat before described for from three to four hours, according to the thickness of the plate, cylinder, or die so exposed; three hours are sufficient for a plate of half an inch in thickness, and five hours when the steel is one inch and a half in thickness. After the plate, cylinder, or die, has been thus exposed to the fire

Mechanical
Processes.

Method of
softening
and harden-
ing the steel
plates, &c.

Manufac-
tures.

for a sufficient length of time, take it from the box and immediately plunge it into cold water. Here it is important to observe that it is found by experience that the plates or other pieces of steel, when plunged into cold water, are least liable to be warped or bent when they are held in a vertical position, or made to enter the water in the direction of their length. If a piece of steel, heated to a proper degree for hardening, be plunged into water, and suffered to remain there until it becomes cold, it is found by experience to be very liable to crack or break, and in many cases it would be found too hard for the operations it was intended to perform. If the steel cracks or breaks it is spoiled; in order, therefore, to fit it for use, should it happen not to be broken in the hardening, it is the common practice to heat the steel again, in order to reduce or lower its temper, as it is technically called. The degree of heat to which it is now exposed determines the future degree of hardness, or the temper, and this is indicated by a change of colour upon the surface of the steel. During this heating a succession of shades is produced, from a very pale straw-colour to a very deep blue. It is found, however, by long experience, that on plunging the steel into cold water, and allowing it to remain there no longer than is sufficient for lowering the temperature of the steel to the same degree as that to which a hard piece of steel must have been raised to temper it in the common way, it not only produces the same degree of hardness in the steel, but, what is of much more importance, almost entirely does away the risk or liability of its cracking or breaking.

"It is impossible to communicate by words, or to describe the criterion by which we can judge of or determine when the steel has arrived at the proper degree of temperature after being plunged into cold water; it can only be learned by actual observation, as the workman must be guided entirely by the kind of hissing or singing noise which the heated steel produces in the water while cooling. From the moment of its being first plunged into the water the varying sound will be observed; and it is at a certain tone, before the noise ceases, that the effect to be produced is known. The only directions which can be given whereby the experimentalist can be benefited are as follows, *viz.*, to take a piece of steel which has already been hardened by remaining in the water till cold, and by the common method of again heating it to let it be brought to the pale yellow or straw-colour, which indicates the desired temper of the steel plate to be hardened. By the above process, as soon as he discovers this colour to be produced, to dip the steel into water and attend carefully to the hissing, or as some call it a singing, which it occasions; he will then be better able, and with fewer experiments, to judge of the precise time at which the steel should be taken out. It is not meant to be understood that the temper indicated by a straw-colour is that to which the steel plate, cylinder, or die, should be ultimately reduced, because it would then be found too hard, but merely that the temperature which would produce that colour is that by which the peculiar sound would be occasioned when the steel should be withdrawn from the water for the first time. Immediately on withdrawing it from the water, the steel plate, cylinder, or die, must be laid upon or held over a fire, and heated uniformly until its temperature is raised to that degree at which tallow would be decomposed; or, in other words, until a smoke is perceived to arise from the surface of the steel plate, cylinder,

or die, after having been rubbed with tallow; now the steel plate, cylinder, or die, must then be again plunged into water, and kept there until the sound becomes somewhat weaker than before. It is then to be taken out and heated a second time to the same degree by the same rule of smoking tallow as before, and the third time plunged into water till the sound becomes again weaker than the last; exposed the third time to the fire as before; and for the last time return it into the water and cool it; after it is cooled, clean the surface of the steel plate, cylinder, or die, by heating it over the fire; the temper must be finally reduced by bringing on a brown or such other lighter or darker shade of colour as may best suit the quality of the steel for the purpose to which it is to be applied."

Mechanical
Processes.

(1093.) *Copper-plate printing.*—The plates, whatever be the nature of the engraving, being finished by the artist, are next to be put into the hands of the copper-plate printer, the operation being performed by what is called a rolling-press.

Copper-plate print-
ing.

This machine, which is of very simple structure, is represented in plate lxxxii. fig. 11. It consists of two parts, the body and the carriage; the former is simply two cheeks of wood, or, as represented in the figure, of iron, A, A, placed vertically on a stand or foot B B, which sustains the whole machine; from this foot proceed also four other vertical pieces, a, a, joined by other cross or horizontal pieces, which serve to support a strong even plank of wood, or table, C D E, about four and a half feet long; two and a half feet broad, and about one and a half inch thick; within the cheeks are two rollers, F, G, the upper one iron the lower wood. These run in the cheeks on gudgeons formed of themselves by turning down their ends, on two pieces of wood in the form of half-moons, lined with polished iron to facilitate their motion. Lastly, to one of the gudgeons of the upper roller is fixed a cross, consisting of two or more levers, H, I, traversing each other at right angles, and by means of which motion is given to the upper roller. The space in the half-moons, left vacant by the gudgeons, is filled in old presses with paper, pasteboard, &c., that they may be raised or lowered at discretion, so as only to leave a space between them necessary for the carriage charged with the plate, paper, and blankets; but in modern presses this is more effectually done by a screw.

Common
press.
Pl. lxxxii.
Fig. 11.

The process of printing is as follows. A small quantity of ink is taken on a rubber made of linen rags strongly bound about each other, and then smeared over the whole face of the plate as it lies on a grate over a charcoal fire. The plate being sufficiently inked, it is wiped over with a piece of canvass, then with the palm of the left hand, then with that of the right, and to dry the hand, and forward the wiping, it is rubbed from time to time in whitening. It is in the wiping that the art of the printer consists; for this must be so effected that, while every particle of ink or dirt is removed from the surface of the plate, the ink already in the engraved parts must not be touched. The plate thus prepared is laid on the plank of the press, and over the plate is laid the paper which is to receive the impression, being first well moistened, and over the paper are laid two or three folds of blanket or flannel. Every thing being thus disposed, the arms of the cross are pulled, and by that means the plate, with its furniture, is passed through between the rollers, which, pressing strong, but equally, forces the moistened paper into the strokes of the engraving, by which it absorbs the ink and receives the impression.

Manufac-
tures.

Some works require to be passed twice through the press, others only once, according as the engraving is more or less deep, or the greater or less degree of blackness the print is desired to exhibit.

The ink usually employed for copper-plate printing is a composition of peach and apricot stones, the bones of sheep or ivory, well burned, (called Frankfort black,) mixed with well-boiled nut-oil, the whole ground together on a marble slab in the same manner as painters grind their paint.

There are usually three kinds of ink, thin, thick, and strong, only differing in their degree of cohesion; the strong is that used in the finer works. The stronger the ink the stronger must be the pressure, and this induces the printer sometimes to use too thin an ink, by which injury is frequently done to the impression.

Perkin's
copper-
plate press—
Pl. lxxxii.
Fig. 12, 13.

(1094.) *Perkin's improved copper-plate press.*—The press described below is the invention of Mr. Perkin, and appears to possess great advantages. The principal improvement consists in a new method of heating the plate or block; in the use of a tympan for the purpose of saving the expense of making the plates or blocks any larger than is necessary to receive the engraving, as well as to save the ink, and also time and labour in changing the plates or blocks. The manner in which these objects are effected will appear from fig. 12, 13. A A, &c., is the cast-iron frame of the press; B the upper cast-iron roller, on the axis of which is fixed the wheel C, with handles around it for the workman to pull by; D the lower cast-iron roller; E F the bed of the press, made partly of cast-iron and partly of wood; the part E is of cast iron, the better to resist the pressure of the rollers, and to convey the heat employed to the warm plate or block; the plate or block G is fixed upon the bed by means of screws passing through countersunk holes made in the bed from the under side of it, and into screw-holes made partly through the plate or block itself. The tympan H is a wooden frame covered with copper, and turning in hinges I, I, having an aperture in it large enough to enclose the plate or block, the sides of which aperture are made feathered edges, so as to overlay the bevelled edges of the plate or block, and prevent them from soiling the paper. The cast-iron part of the bed of the press, with the plate or block upon it, is heated by means of a block of cast iron, which is supported upon another plate with turned-up edges, and which block is removed and replaced by another from time to time as it cools. In use, the frame of the plate is inclined, the front end resting upon the floor, and the other being raised by two screws passing through screwed holes in the sill of the press frame, one of which screws is shown at L. The intention of this inclination is to cause the bed to return, after the impression is made, of its own accord; and, in order to admit of this, a portion of the roller B is removed, and three pair of additional rollers, M, are added for the bed to roll upon with more facility, each pair of rollers being fixed upon a separate axis, with the necks working in brasses.

The blankets N, N, are secured to the cast-iron bed at one end by the blanket-holder O, and the stretcher P is affixed to the end of them, from which cords, Q, pass over the pulleys R, R, and have weights, one of which is shown at S, hung to them. By this means the blankets are kept stretched and relieved from the roller, and prevented from matting or becoming dirty in use. The roller B is kept up when the bed is released by the two following contrivances: T is two wooden blocks

lying at the bottom of the chases in the press frame; Mechanical at each end of these blocks is fitted a screw nut, into Processes which are screwed two screws, having flat cylindrical heads, with notches or teeth cut around them, and which project beyond the sides of the press frame so as to be easily turned either way as required. Upon these heads the brasses are rested in which the necks of the axis of the roller B turn, and the roller can thereby be supported at the required height, as above mentioned.

Fig. 13 represents a cylindrical steel or copper-plate printing press; A A, &c., is the cast-iron frame of the press; B the main cylinder for holding the plates, which has a solid cast-iron cylindrical surface or rim, upon which the plates are firmly secured by means of screws fastened through holes made in the surface of the cylinder, from the inside of it, and entered into screw-holes made partly through the plates. The main cylinder is mounted on an axis with necks, each end of it turning in brasses fixed upon the tops of the two main upright standards of the press frame. C is the small cast-iron pressing cylinder, which can be adjusted so as to press with more or less force against the main cylinder B by the screws, one of which is shown at D; E E is the endless web or blanket passing over and carried forwards by the pressing cylinder C, and over the web cylinder F; the necks or axis of which cylinder turns in brasses fitted into sliding carriages with adjusting screws, one of which is shown at G, for stretching the web.

Upon the extended axis of the pressing cylinder C is fixed the drum or rigger H, which is driven by a band. I I receives its motion from the moving power. The plates J, J, &c., are inked by the roller K running into contact with them in succession as the main cylinder revolves, and which roller is inked from distributing rollers L and M, the latter of which receives the ink in the usual manner as printing machines, from a trough and ductor, and which therefore need not be here shown. The ink is more uniformly distributed over the plates by a hand-roller used by a workman; another ductor N is supported by baskets at each end of it to the main standard of the frame, in the manner used in calico-printing. The last-mentioned ductor scrapes or takes off the larger portion of the ink, the remainder being removed by several persons wiping it off in succession, and finally cleaning their surfaces in the usual way. The paper, properly moistened, may either be laid on the revolving web or blanket E E in sheets, and be taken away when printed, or may be in the form of one or more long sheets, which may be previously wound upon the reel P, the neck or the axis of which turns in semicircular gaps or notches, one of which is shown at Q, and passes below the ductor-roller R until it reaches the prop, after passing through which, and becoming printed, it finally passes over the roller S to be taken away. The courses of the endless web or blanket E E, &c., and of the long sheet of paper, are indicated by the arrows which are shown accompanying them in their progress. The standards which support the neck of the rollers K, L, M, N, are omitted in the drawing, but must of course be employed. *Newton's Journal of Arts.*

(1095.) *Machine for numbering bank-notes.*—The Bank of England notes are of course first printed from a copper plate, as described in the last article, but the numbering, dating, &c., are afterwards printed by a machine invented by the late ingenious Mr. Bramah. Machine for numbering bank-notes. Pl. lxxx. Fig. 6.

Manufac-
tures.

This machine was first described by Mr. Farey, in Rees's *Cyclopædia*, and again in Brewster's *Encyclopedia*, and has since been introduced into other Works of the same kind. The following abridged description is obtained from these sources. It was formerly the custom in the Bank of England to fill up the number and date of their notes in writing; but, in 1809, the machine we are about to describe was invented for this purpose by Mr. Bramah, and has since been constantly employed. The copper plates from which the words of the notes are printed are double, that is, they throw off two notes upon one long piece of paper; this paper, containing the two notes, is put into the machine, which prints upon them the number and date, the date remaining fixed for the day, but the number changing, one for every succeeding note printed. The number on the note is always repeated; it is first found over the words *I Promise*, and again over the word *Bearer*. Any number being thus printed, the unit figure changes to the next in order, then again to the next, and so on, till the change is required in the tens' place, so that without much attention on the part of the operator, and without the possibility of error, the numbering and dating are executed in the simplest manner imaginable, and with more than six times the expedition with which the same could be effected by hand. This is of great importance, and was more especially so during the issue of the one-pound notes. The machine by which this operation is effected is represented in section, as for a single note, in plate lxxx. fig. 6; it is only necessary to consider this of double length, and with two sets of circles, to form an idea of the machine for two notes, as above described. A A is a solid base of mahogany, to which the sides of the machine are securely and firmly screwed; these are cast iron, one only of which is of course seen in the figure. From one side to the other of the machine are three axes, H, C, D; to the latter is attached the handle F, which is raised and depressed by the operator, who is a clerk in the Bank; to this is attached the tympan E. When the handle is raised this plate may be opened, and the note to be numbered is introduced and placed in its proper situation by means of two guide pins; the plate is then shut and the note properly confined, there being two holes in the plate to allow the types containing the numbers to come in contact with the paper.

On the axis C are five brass circles, of which only one is seen in the figure; each of these has eleven teeth, in which are cut notches to carry the digits 0, 1, 2, 3, 4, &c., 9, and one blank; the other wheel H on the axis H has also eleven teeth, so that moving one tooth on the latter turns the other one tooth round. There are three wheels on the axis, although only one can be seen, two of which are in contact each with one of the brass wheels on the two ends of the axis D, and the other is a central one by which the motion is communicated. This motion is thus produced: when the handle F is raised nearly perpendicularly, where it is stopped by the fixed stud *d* coming in contact with the back of the handle, the tooth or claw *b* will have passed the upper tooth of the wheel H, which it does without resistance, in consequence of its freedom of motion on its joint; but in returning the handle to its horizontal position, the claw having no motion in the opposite direction, it catches the upper tooth and forces it round the interval of one tooth, and this again forces the wheel C also one tooth, and consequently changes the number one place, that is to say, from 0 to 1, or from 1 to 2, &c., the several types

being arranged in order round the wheel. Of the five circles on the axle C, for example, let us suppose the four right-hand ones to have their blank teeth all up, and that the tooth 1 is upon the right-hand wheel, and suppose the impression No. 1 made at the two ends or sides of the notes by the two outside wheels, and that the wheel H is in contact with these two outermost circles. Then the handle being thrown back, the note removed, and another introduced, the claw *b* will have passed the upper tooth of the wheel H as above described, and on returning it will catch and press forward this wheel one tooth, and this again the wheel on C, bringing now the digit 2 to the upper position; the impression being made, the same process, if repeated, will bring up No. 3, then No. 4, &c., to No. 9.

It is now necessary, having run through all the units, to bring up No. 1 on the wheel, which now becomes the tens' place, and which is done by making two strokes with the handle without printing; the axle H is now pushed on end by a proper nut so as to bring the wheel H in contact with the next brass circle; then, the blank being already up, the next stroke brings up the 0, making with the standing digit 1 the No. 10; the next stroke gives 11, then 12, 13, &c., to 19. The first wheel is now moved on by hand till 2 is the uppermost type; then, similar steps being followed, the Nos. 20, 21, 22, &c., are obtained, and lastly, 99; when the first wheel *a* becomes the place of hundreds, the second of tens, and the wheel H is again put on end to engage the third type wheel, and so on, to any extent short of 100,000, 99,999 being, of course, the highest number to be attained by five type-wheels only. There are some minutiae about the machine which it is difficult to describe without other drawings; but the general nature of its operation will, it is presumed, be tolerably well understood from the preceding description.

Lithographic Printing.

(1096.) Lithographic printing is a modern Art, the invention of which is due to Sennefelder, who made the discovery about the beginning of the present century; but it is only since the Peace in 1815 that lithography began to be considered of sufficient importance to be classed amongst the Fine Arts. The principles on which it rests are thus stated by Mr. Partington, in his *Engraver's Complete Guide*, viz.

1. That a line drawn with a pencil or fat ink on a stone adheres to it so strongly that mechanical means must be employed to remove it.
2. All those parts of the stone which are not covered with a layer of fat or grease receive, retain, and absorb water.
3. If over a stone so prepared a layer of greasy and coloured matter be passed, it will attach only to the lines made by the greasy ink, while it will be repelled by the wetted parts.

In fact, the lithographic process depends on the circumstance that the stone which has imbibed the water repels the ink, and that the same stone, when greased, repels water and holds ink. Thus, by applying and pressing a sheet of paper on the stone, the greasy, resinous, and coloured lines alone will be transferred to the paper, giving the counter-proof of what they represented on the stone.

By making a drawing on paper with prepared ink, and transferring it to the stone, impressions exactly like

Mechanical
Processes.

Principles
of the Art.

Manufac-
tures.

the original may be obtained, that is, not reversed, as is the case in engravings on copper.

All kinds of stone susceptible of being penetrated by a fat substance, and of imbibing water with facility, are proper for lithography, provided they are compact, take a good polish, and are of a light and uniform colour: all these advantages are found united in certain calcareous stones, which are furnished in abundance by the quarries of Solen-Hofen, near Pappenheim, in Bavaria. It is a carbonate of lime almost pure; and is found also in other places.

When the stone is prepared and polished, the artist may, without any other preparation, sketch his design as he pleases, and finish it with the crayon, the pen, or the pencil. The grain of the stone being uniform, and finer than the finest wove paper, he may execute his work in the most delicate manner: but sufficient stress cannot be laid upon the fundamental principle of the Art, for, well as the rules are known, they are still continually forgotten by artists, who think that, provided the drawing they have executed looks well to the eye, they have done all which is necessary, and that the printer must and can do the rest, forgetting that the face of the stone has, perhaps, been soiled during the execution of the drawing, either by chalk cuttings, by rubbing with paper kept under the hand, by perspiring fingers, and many other causes of failure, which occasion spots, that disappear the moment they have soiled the stone, to re-appear again, infallibly, in the printing. The artist is surprised at seeing all those spots come forth, and accuses the printer of that which proceeds entirely from his own want of care. It is clear that, were it not for the black contained in the chalk, an almost invisible drawing might be made on stone, which would come forth only in the course of printing: and this is the case with those spots which do not form part of the drawing, and have taken place from negligence; as they do not show, the artist considers them of small importance, and, entirely taken up with the drawing he is executing, he hopes and thinks that nothing will print but what he intends should print. Therefore, again let this plain truth be enforced, that a lithographic stone absorbs, with avidity, any grease applied to its surface, and, consequently, that any grease or dirt so applied will come forth in the printing, as well as that grease which is intended to constitute the drawing.

We have now to notice the various species of stone employed in the Art, and upon the choice of which the success of the work must materially depend.

Ink drawings are generally made on polished stones, as the grain necessary for a chalk drawing makes it unpleasant to draw with the hair pencil or the pen. Some persons, from ignorance, have made chalk drawings on a polished stone; these, however, invariably fail, as a stone with a proper grain is the first requisite for the success of a chalk drawing.

It is of the greatest importance that the grain of a stone for a chalk drawing be not too fine, and a little practice will soon show the artist which is the proper grain; if too coarse, the drawing, particularly the delicate tints, will look open and sandy, and the execution will be attended with great trouble, especially in making out the minute parts. On the other hand, if the grain be too fine, the chalk slips and draws greasy, the stone does not appear to bite, and there is difficulty in producing dark tints. Moreover, in the printing, the darker parts soon clog up, and from the stone approach-

ing to the polished state, the delicate tints do not hold, and soon break up. The ease with which chalk works on a well-grained stone will soon teach an artist to know when the grain is as it ought to be, and its facility is such as to make drawing with a pencil on paper afterwards meagre and poor; for there is a richness and fulness in drawing on a good stone, which, from the nature of the material, has more of the feel of painting with a brush than of drawing with chalk. This peculiar feel is the best criterion to judge of the right grain of a stone.

There is no difficulty in ascertaining the proper preparation of a polished stone, as it is sufficient that the face be well smoothed and free from scratches.

This last defect is also to be avoided in a grained stone, as scratches are often produced by a coarse grain of sand, which invariably prints like a white hair line.

Although it is impossible to draw with chalk on a polished stone, ink may be, if employed with judgment, applied with great advantage in chalk drawings.

The best way to see the grain of a stone is to incline it to the horizon, nearly at an angle of 45 degrees; by varying the position slightly, above and below this angle, a certain point will be found at which the light will catch all the little asperities, and show the grain very distinctly. An artist who will take the trouble to do this with every stone he works upon will learn to know, by the eye, whether the grain is too fine or too coarse.

Portraits admit of, and even require, a coarser grain than landscape, particularly if drawn in the stippled manner. Success is more certain, and the impressions will possess a degree of brightness which can never be attained with a finer grain. By employing a sharp-pointed pencil for the more delicate tints, and occasionally opening and picking with a needle those small specks which occur in working on a coarse stone, a clever artist can produce drawings which bear being placed next to the best specimens of copper-plate engraving.

It must, however, be borne in mind, that in every case, whether figures or landscape, a coarse-grained stone is by far a less evil than too fine a one, as a failure is often the consequence of too fine a grain; whereas a little more trouble in the execution of the drawing is the only risk which the artist runs in working on a coarse grain.

Dr. Forster, of Berlin, is, we believe, the first person who has published his own Work, written by his own hand. It is entitled *An Introduction to General Geography, and preparatory Lessons of Geometry*, by Dr. Frederic Forster.

The author apologizes for his hand-writing in the following terms: "This book appears as a fac-simile manuscript. Young readers will not find the few pages fatiguing to their eye, and elder readers are accustomed to the reading of letters written in less clear and legible characters than mine. We do not find that writing, provided the impression be good, fatigues the eye."

The great convenience of being able to insert the figures between the writing, in mechanical and mathematical works, shows itself here to advantage; and it is probable that other works, requiring figures, plans, calculations, &c., will be executed on stone in a similar manner.

(1097.) *Description of the press.*—A A A, plate lxxxii. Lithographic press, fig. 14, are the supports of a strong table, on which is

Mechanical
Processes.

Manufac-
tures.Pl. lxxxii.
Fig. 14, 15.

placed the cast-iron press, consisting of two heavy iron sides, B C B, which are securely attached by screws to the centre part D D, which is also a thick cast-iron plate with a hole in its centre, as shown in the figure; from the sides are continued two iron slides *b, b*, only one of which is seen, and on these slides and a roller beneath, attached to the handle H H, the bed of the press G moves; E E is a frisket, beneath which the stone is laid, resting on the bed; there are screws and nuts at *tt* by means of which the sheet of leather, by which this is formed, may be brought to a proper degree of tightness; the handle M (shown larger in fig. 15) is hung on a joint at J, having another joint at K, and the descending axis S has a piece of hard wood fixed to it below, and which is adjustable by means of a nut running on S, so as to produce the proper degree of pressure.

It will be seen that when the handle M is pulled down, as represented in the press, the joint K (fig. 15) comes vertically below J, and the board I is depressed so as to press with the required force upon E E. Supposing now the handle M down, as in the figure, the handle H is turned, and the bed is carried, by means of the rollers upon which the bed rests, below the frame D D and board I, and thus receives sufficient pressure to deliver the impression. The handle M is now thrown up into the position shown in fig. 15, when (the pressure being thus removed) the bed is easily drawn back again over the rollers, and slides into the position shown in the figure. The frisket is now opened, the impression removed, another plain sheet is then introduced, the frisket shut down, and the handle M is again depressed, when, by means of the handle H, the bed is again rolled through and another copy taken, and so on. There are various forms of these presses; the one described is, perhaps, as simple as can be desired.

Gem en-
graving.

(1098.) *Gem engraving.*—Having described all those kinds of engraving intended for producing multiplied copies on paper, we propose to conclude this article by a concise account of some other kinds of engraving, *viz.*, as gem engraving and die sinking, which is also a species of engraving. In gem engraving, the diamond, which is the hardest of all stones, is cut only with its own dust; in some others emery may be employed. In shaping or cutting rough diamonds, the first thing to be done is to cement two such stones to the ends of two sticks large enough to hold them steadily in the hand, and to rub or grind them against each other till they are brought to the desired form. The dust or powder thus rubbed off is to be preserved, and is employed afterwards to polish them. This is performed with a kind of mill, which turns a wheel of soft iron. The diamond is fixed in a brass tool or dish, is covered with its own dust mixed with olive oil, and is thus applied to the wheel, first on one face and then on another, till the desired polish is produced.

Rubies, sapphires, and topazes are cut and formed in the same way on a copper wheel, and polished with tripoli diluted in water. Other softer stones, as agates, amethysts, emeralds, hyacinths, &c., are cut on a leaden wheel with emery and water, and are polished with water on a pewter wheel, and lapis lazuli, opal, &c., are polished on a wooden wheel. To fashion and engrave vases of agate, crystal, lapis lazuli, or similar stones, a lathe is made use of to hold the vessels, which are to be formed with proper tools; but in engraving the tools are applied to the lathe, and the subject under operation

is held against it by the engraver, the tools being moistened from time to time with diamond dust and oil if necessary, but commonly with emery. To engrave figures or devices on any of these stones when polished, such as seals, &c., a small iron wheel is used, the ends of whose axis are received within two iron cheeks placed upright as in the common lathe, so that they may be brought nearer or set further apart at pleasure, and at one end of the axis the proper tool is fixed by a screw, which will allow the tool to be readily changed; this wheel being put in rotation by the foot, the stone is applied by hand to the tool, its position being changed and ordered as the work to be performed requires.

The tools used by gem engravers are commonly iron, but some are of brass, and generally resembling chisels, gouges, &c.; others are like ferules, to take the pieces of stone out; others flat, &c. When the engraving is finished, it is polished on wheels of hair brushes with tripoli.

(1099.) *Die sinking.*—This is also a kind of engraving Die performed on punches, matrices, and dies proper for striking medals, coins, and counters. The method of proceeding is the same in all these cases, at least the only difference consists in their greater or less relief; this, in coins, being considerably less than in medals, and in counters commonly less than in coins. The engraver in steel usually begins with punches which are in relief, and serve for making the creux or cavities of the matrix and dies; sometimes, however, he begins immediately with the creux, but it is only when the intended work is to be cut very shallow. The figures are designed and moulded in white wax of the size and depth required, and from this model he graves his punch, which is of steel, or of steel and iron mixed in certain proportions; the intended design being formed on this in its soft state, it is then rendered hard by a proper tempering.

The instruments used in this relief engraving are much the same as those wherewith the finishing the work in creux is effected, and are of steel; the principal are gravers of different kinds, chisels, flatters, &c. When the punch is finished, and the proper temper given to it, it is ready for being employed in sinking the matrix, which is effected by blows with a hammer.

The matrix must be a piece of good steel, of a cubic form, whereon the relief of the punch is struck in creux. This steel must of course be rendered as soft as possible by being made red-hot, that it may the more readily receive the impression which is given to it in this state; it is afterwards improved by the graver till the desired effect is produced; it is then hardened, and is fit for use.

Modelling and Sculpture.

(1100.) It is not our intention in this place to treat Moulding of these subjects as branches of the Fine Arts, which has been already done at length in another Division of this Work; our object is simply to describe the mechanical processes which are pursued with a view to produce the desired effect. There are several forms in which statues, busts, &c., are exhibited: first, in plaster of Paris or other material of a similar kind; secondly, in brass, bronze, or other metal; thirdly, in marble or other stone; we may also add, fourthly, in wood. In all these cases, the first process belongs entirely to the artist, who provides himself with a lump of clay with which to model the intended figure, and having first, by a drawing,

Mechanical
Processes.

Manufac-
tures.

sketched a general idea of his work, he proceeds to execute the same in clay of the full size. In this part of the process his tools are of the most simple kind, made of wood or ivory, with their ends pointed, round, square, or diagonal, with which, having by hand reduced the clay to something like what is required, he produces the more minute effects of form and expression. It may be remarked, that if the clay model is large, it must be supported by framework to prevent its bearing wholly on its own base, and the masses of clay must be kept together by a number of small wooden crosses attached to the framework by wires of different lengths dispersed through various parts of the clay.

Making the
mould for
casting.

When the clay model, which we will suppose to be a bust, is finished, it must be moulded or cast, or rather, perhaps, cased, with a covering of plaster of Paris. To effect this, some plaster is made up very thin, not thicker than thin cream, and with this the statue is cased. It is to be observed, however, that, to facilitate the removal of this case afterwards, the principal part behind is separated from the front by the following contrivance: a thin edge of clay is laid along the figure from the head to the base, and the front is first completed up to this ridge of clay, the moulder carefully casting the thin plaster into the recesses in the eyes, ears, nostrils, &c.; a thicker plaster is then thrown on till a thickness of two or more inches is obtained; the ridge of clay is now removed, the edges of the plaster slightly touched with oil, and then the back is covered in the same way till the whole becomes a shapeless lump of plaster of Paris of considerable thickness and weight, and forming externally one solid lump.

This single lump is now separated by a few blows with a mallet and chisel, and the mould thus divided into two parts. The clay figure is then broken out, and the two parts cleaned to remove all the clay from the smaller recesses, and the inside slightly touched with oil in all the more delicate parts. The two halves are then replaced and bound together with cords, and a complete mould thus obtained of the original clay figure. A quantity of plaster is now poured in and rolled about so as to form a thin coating; then more is added, then more, and so on, till a sufficient thickness is given to the internal figure. The mould must now be broken off, an operation which requires great care, in order to avoid destroying any part of the interior figure. This is done with a chisel and mallet, by which piece by piece is removed till the interior figure is produced a perfect copy of the original model.

If the work thus obtained is intended simply for the guidance of the sculptor, this part is now completed, and the operation of the sculpturing proceeds as described below; but if it is intended to obtain from it other cast figures in plaster, another mould, called technically a *safe mould*, must be made. This is formed in detached pieces, something after the manner described for casting brass statues, (Art. 924.) so that after a figure is cast the mould may be removed piece by piece, and then put together again to cast others in the same way. It may be asked, when the object is simply to make plaster casts, why is not this done in the first instance? The reason is that the clay model has not sufficient resistance in it to bear the operation. Copying this model is the work of the sculptor, and by different artists is conducted in different ways as far as regards the removal of the large portion of the block, till an approach is made to the figure; from this last stage the genius and

Sculp-
turing.

talents of the operator must be exercised according to rules altogether independent of mere mechanics. Mechanical
Processes.

The former mode of copying was as follows: a number of small black points were marked upon the model in every principal projection and hollow, to give the distances, heights, and breadths sufficient to copy the model with the greatest exactness. The Ancients, it is said, performed this by considering every three points on the figure as a triangle, which they made in the marble to correspond with the same three points in the model, by trying it with a perpendicular line, or some fixed line, both in the marble and the model.

Our present artists, as we have said, use other methods. According to one, after having by rough measures ascertained that the block is of sufficient size, it is fixed on a basement of stone, or a strong wooden bench called a *banker*, in front of which is a long strip of marble divided into feet and inches. A strip of marble, divided exactly in the same manner, is placed below in front of the model, and a wooden perpendicular rule the height of the work, which is movable from the strip of marble or scale under the model to that under the block of marble which is to be cut. This rule or instrument being first placed on the scale of the model, and the exact distance taken from it to any prominent part, as, for instance, the end of the nose, is then removed to the corresponding position of the other scale, and the workman cuts away the marble to the same distance from the perpendicular at the same height, that is, till he has arrived at that point of the block which is to become the tip of the nose. He then proceeds in the same way with another prominent part, as the top of the head, the chin, &c., till he has fixed all the more prominent or principal parts; he then proceeds to other parts till he has at length obtained a rough figure, containing within it all the other minutiae which remain to be brought out by the more skilful hand of the master.

(1101.) *Machine used by sculptors.*—A more rapid and, perhaps, more exact mode of obtaining the first rough outline has been adopted by some artists. The model and block being arranged on the banker in the same line, a brass frame is placed in front, on which slides a perpendicular, also of brass; this carries a tube through which a rod passes, and which is brought in front of the model, and the point applied to any part of the bust; the point being set, a screw is run down to fix the distance exactly. The instrument is now placed in a corresponding position in front of the block, and the position of the point marked by the end of the rod. A hole is now drilled in the block in this place, till the depth of the hole is such as to allow the instrument to reach by its stop the ruler in front; the exact point in the block is thus obtained. Another point is now taken, and the block drilled in the same way till the whole becomes like a piece of honeycomb; and these parts being now cut away with the chisel, taking care never to remove any part below where the drill has been, the figure in its rough state is fit for the hand of the sculptor.

Another exceedingly ingenious method has been proposed by Mr. Behnes to the Society of Arts, for which he received their gold medal, and which is described in their *Transactions*, vol. xxxvii. This is represented in plate lxxxiii., fig. 1, 2; the former showing the model, and the latter the marble block in the progress of working. The nature of the instrument and operation will be sufficiently obvious by simple inspection: F is what we have described as the banker; S S, fig. 1, 2,

Behnes's
machine for
sculpture.
Pl. lxxxiii.
Fig. 1, 2.

Manufac-
tures.

blocks of stone, to which are securely fixed the semi-circular cast-iron beds E, E; these two beds, *viz.*, under the model and under the block, being made very exactly alike; G, G are cylindric holes in the iron beds, also exactly the same size, to receive the axis of the instrument as represented by the dotted lines; this is retained in its place by a catch, but is removable at pleasure so as to fix the instrument itself in front of either figure. The tube H, which is attached to the axis, receives the tube B of the instrument, and is held in its position by the two clip screws seen in the figure. On the upper part of the tube B is a cap M and a set screw *m*, by means of which the upper part or circle D may be turned in any position, and then fixed by the screw to that position. On the axis D is another clip tube N and set screw *n* for receiving, adjusting, and fixing the small cylindrical tube C; and *d* is a stop adjustable on the arc whereby the instrument after being turned back, as shown in fig 2, may be returned to its position. Q is a triangular socket in which slides the needle P, and *q* is a small set screw or stop to fix its position forward, but allowing its being withdrawn; this turns by means of a ball and socket O screwed firmly at right angles into a cylindrical cavity at the extremity of the lesser cylindrical tube C; this gives the needle containing the gauging point a complete circular motion for all angles less than 90°. The position in any case being taken, the motion of the ball in the socket is prevented by turning the screw *r*. It is only necessary further to add, that the first tube H is fixed in any required position by small studs at its back, not seen in the figure, which are inserted into the corresponding holes in the plate, the front of which is of gun metal securely screwed to the cast-iron beds.

The method of using the instrument is now obvious; the tube H is fixed by inserting its axis into the hole G in the plate under the model, and the studs at its back into the proper holes in the arch, according with any convenient position for the large tube B; this tube is in like manner raised or depressed to any required degree by sliding it in the tube H, and is then made fast by the set screws *h h*; the small tube C and the axis D are now also conveniently arranged for taking any proposed point of the model; the latter is then fixed in its place by the set screw *m*, and its position marked by the adjustable stop *d*, whereby, after being turned back, this tube may be brought again to the same position. Lastly, the needle may be directed to any point of the bust by means of the ball and socket joint, and is then made fast by the screw *r*. The needle being now at its point, the stop *q* is adjusted and fixed, which prevents the needle from advancing, but admits of its being drawn back. The instrument is next removed to the bed under the block, the axis introduced into the hole G, and the studs into the corresponding holes to those in its former position, fig. 1. Every thing remaining as before, except that the needle P has been drawn back, this is now advanced, and the point in the block ascertained on which the operation is to commence, and where the marble must be cut or drilled away till the needle can be advanced to the position marked by the stop *q*; another point is then to be taken, and so on till the block is reduced to the state for receiving the last touches of the master.

On this subject, perhaps, we ought to say but little; we may, however, add, that the sculptor now proceeds to work over his bust or statue with a flat-ended steel tool

called a chisel, the end being about five-eighths of an inch broad. In the naked parts of the statue, and wherever there is a flat surface, he cuts away the rough surface from a given point in a straight line to another point at some distance; he then cuts away the surface from one given point to another exactly parallel to the course his chisel went before; he then cuts the marble in a line at right angles with the former direction of his chisel. He continues to work over the surface in this manner, always cutting the lines parallel to each other, leaving the space of about the eighth of an inch between each course of his chisel. He then cuts away the remaining rough surface, leaving about one-eighth of an inch between each two courses; thus obtaining a beautiful flat surface to his work, which can be obtained by no other means, but may be afterwards varied with the curvatures and indentures of the minor parts at pleasure.

This method of cutting the stone is followed as much as possible in all parts of the work; that is, as much as all the variety of outline and hollows will permit. When the latter are so deep and intricate that they cannot be cut out with small chisels struck by the hammer, drills of different kinds are employed to produce the rough hollows, which are afterwards finished with the hammer and chisel, or by long tools fixed in wooden handles, used by the hand only, without the hammer.

A particular dexterity is required in producing the different characters of the hair with the chisel to make it look light and soft, curled or plain, which is, however, done by the hand of the experienced sculptor with nearly the same effect as by the painter in laying on his colours with the pencil. The finishing of flesh in imitation of the fulness of muscle, the apparent pliability of the softer parts, the greater or less durability of tendon and bone, may also be represented in marble nearly to deception; but to effect this the sculptor must be well acquainted with the structure and appearance of the parts he represents, and accurate in copying the object of his imitation.

The last finish to the marble in the modern practice of sculpture is performed by the use of rasps, and afterwards of files; the best rasps for sculpture are made in Italy, their teeth being cut more sharply than those made in England, at the same time that the ends of these rasps and files are capable of being bent in any form, according to the use for which they are to be employed; if the piece of sculpture is required to have an exceeding smooth surface, the pumice stone is used after the file; and sometimes the whole surface is rubbed or ground carefully over with small pieces of grit stone, accommodated to the various forms of the surface, as to flat spaces, rounds, and hollows of different depths. But the hair in all cases must be finished with the tool; and for this purpose, the edge of the tool must be sharpened with great accuracy and acuteness; and if it is required that the work should be very highly finished, the last edge of the tool must be given by an oiled Turquoise stone. Chisels may be sharpened for the different kinds of work, either on one side or on both, horizontally, diagonally, circular, or pointed. The sculptor uses large square four-footed strong stools with tops, which turn round upon little balls of brass or iron, on which he places the marble statue he works on; his tools are steel chisels of different sizes and lengths, their ends being from an inch broad, and diminishing in succession till they become perfectly pointed. These are worked with an iron-headed hammer, weighing from

Mechanical
Processes.

Method of
using the
chisel.

Manufac-
tures.

two to four pounds, according to the heaviness or lightness of his work. The first tools used in wasting away the marble are strong steel tools, sharpened nearly to a point, which, being struck with a heavy hammer obliquely, knock off the waste marble in much larger pieces than a broader pointed tool would do. The practice of the sculptor also requires the frequent use of the square and compasses, as his own ingenuity may direct.

Miniature
ivory busts.

A very ingenious method of reducing and copying busts and statues (at least if we may judge from the results, for the method itself is not made public) has been lately introduced and practised in London; whereby any large bust or other figure is very exactly copied in miniature in ivory, of one-sixth, one-eighth, or one-tenth of the linear dimensions of the original figure. The exhibitions of these miniature busts, which we have seen, are exceedingly satisfactory; the likeness is most correctly preserved, and the surface and finishing very beautiful. The machine and process employed is a secret in the keeping of the inventor, and we can, therefore, only conjecture what they are; and as these conjectures may be erroneous, we think it better to leave the subject without description than to describe it incorrectly.

Modelling
in wax.

(1102.) *Modelling in wax.*—This may be considered as a branch of sculpture, inasmuch as it affords patterns and examples for very numerous articles of Fine Art in metals. Although, from the nature of the material, no wax model of the Greek or Roman times has come down to us, they must have been almost innumerable during the best Ages of Greece and Rome, judging only from their small figures of divinities in bronze, of which, perhaps, upon an average, every person, rich and poor, might have half a dozen; so that the amount of these small images from patterns of wax would be nearly six times in number of the population of the civilized world at any one period. Wax modelling, besides, is required for the patterns of all goldsmiths and chasers of ornamental work upon a small scale; all the fine medals of the Popes were copied from small models in wax of the most distinguished sculptors. To make the best modelling wax, take two cakes of virgin wax, break them in pieces, put them into a clean pipkin, and the quantity of the smallest hazle-nut of Venice turpentine and about double the quantity of flake white reduced to the finest powder; place the pipkin over a slow fire till the wax is melted, stir the composition together, and it is the best wax which can be used for modelling. Models of different-coloured wax may be made by putting pounded red, blue, yellow, &c., instead of flake white, according to the colour required; the same instruments are used for wax modelling as for clay, viz. wood and ivory nicely pointed. Sculpture in bronze and silver is practised in the same manner by the Moderns as Pliny describes it to have been by the Ancients, and is of three kinds; the subject is either cast from a model, or carved from the solid metal, or otherwise chased from a model upon a flat piece of metal, which is beat hollow on one side to produce the relief, out of which the chaser works the intended figure or figures on the other side. The instruments used in chasing are, for small work, a small hammer with a long elastic handle, which gives the blow a quick and artificial force; also chisels and points, somewhat like those used in sculpture of marble on a smaller scale. The tools for carving in wood are so universally known to carpenters, upholsterers, and the different orders of wood carvers, that the description of them would be useless.

Lens and Speculum Grinding for Telescopes.

Mechanical
Processes.

(1103.) It is well known that the object-glass of an achromatic telescope is composed of two lenses, one of flint glass and the other of plate or crown glass; which, having different refractive and dispersive powers, may be so proportioned in their curvatures that, while from a combination of the two the rays are brought to a focus, the greater dispersion of the flint lens may be corrected by the less dispersive power of the plate, the one being negative and the other positive. The plate is the convex lens; that is, the sum of the reciprocals of the radii must be positive, although one only may be a convex surface; and, on the other hand, the flint must be negative, that is, the sum of the reciprocals of the two radii must be negative; the radii in both lenses being accounted negative when concave, and positive when convex. Moreover, the length of the positive focus of the plate must be to the negative focal length of the flint in the exact ratio of their dispersive powers, in which case the lens becomes achromatic or free from colour.

Grinding
glasses
and specula
for tele-
scopes.
General
principles.

There is, besides, another point to be attended to in proportioning the curvatures of lenses for refracting telescopes, which is what is called correcting the spherical aberration. The refractive power of the glass bends the rays of light falling on or rather entering its surface, according to a certain law; which is such that the sine of the angle at which the ray meets the surface is to the sine of the angle in which it proceeds in the medium in a given and constant ratio while the glass is of the same kind; but it differs greatly in different kinds of glass, and even in different specimens from the same furnace. The same occurs again when the ray, having passed through the lens, arrives at the other surface and passes into air, the ratio here being the inverse of the former. Now the angle at which the ray meets the surface is the angle of the ray with the tangent of the surface, and this is of course different at points of the lens, at different distances from the centre; so that when the lens is of considerable dimensions the actual angles of incidence and refraction are different, and the rays do not all proceed therefore to the same point, as they ought to do for perfect vision. For example, taking any single point in an object, the rays from this single point diverge and fall on every point of the object-glass; they are then, on entering the glass, refracted according to the law above stated, and again on arriving at the other surface, and bent to a focus. But this focus is, for the reason above stated, not an individual point but a succession of points one behind the other; or, if the convergency of the rays be intercepted by a plane instead of a point, we shall have a small circle to represent what ought to be only a single point, and thus a certain degree of indistinctness is introduced into the image; for, the same happening for every individual point of the object, every one will be in part blended with those adjacent to it; and this effect, which is unconquerable in a single spherical lens, is what is known by the term spherical aberration of the lens; but this defect like the former, viz. the chromatic aberration, may be corrected by a double lens formed of two kinds of glass having different refractive powers, or, at least, if it cannot be entirely destroyed, it may be rendered very inconsiderable. The reason why it cannot be wholly corrected is, that the curvatures requisite to effect it depend upon the indices of refraction, and these indices being different for the different coloured rays, the curvatures that will correct the red ray, for

Manufac-
tures.

instance, will not correct the violet, and the converse; opticians, therefore, correct the mean or green ray, leaving the others to their fate, and consequently the one is over, and the other under corrected.

A similar imperfection arises in the first correction we have pointed out for achromatism; this arising from a want of uniformity in the coloured spaces of the spectra in glass of different dispersive power, some of the colours in one spectrum bearing a very different ratio to the whole to what happens in the other; the length of the violet, for example, bearing a much greater ratio to the whole length of the spectrum in one than in the other, and the same more or less for all the colours, so that the curves which correct the one will not correct the other. This subject is treated of with great precision in our Treatise on OPTICS, and will not, therefore, require any theoretical illustration in this place, where we only propose to describe the mechanical processes by means of which that theory is reduced or applied to practice. At the same time, merely practical rules for grinding, polishing, &c. would be useless, without also giving rules for determining the proper radii of the tools; for the best workmanship would be thrown away upon wrong curvatures, as the most profound theory would be without perfect surfaces. Referring, therefore, the reader for every point connected with the theory of the telescope to our Treatise on OPTICS, we shall proceed to give simple practical rules for determining the curvatures, and afterwards a description of the mechanical processes by which these curvatures are to be obtained.

Method of
finding
the refrac-
tive index.

(1104.) *Determination of the refractive index.*—Before the first step can be taken towards the construction of a refracting telescope, the index of the refractive power of the plate and flint glass intended to be employed must be determined. This may be done in different ways, viz. by employing small prisms of the glass in an instrument called a goniometer, by measuring the focal length of a line of known curvature, and by other means described by different writers; but that of measuring the focal length is by far the most simple, and most consistent with the practical optician's means of measuring, and which, therefore, we describe in this place from an article on this subject by Mr. Barlow, given in the *Phil. Trans.* for 1827. The author observes, "The following method of determining the index of refraction, by means of a lens, is not given as new; it has, on the contrary, been long practised; but as it forms the foundation of the method for determining the dispersive ratio, and will occupy but a few lines, I shall be excused for introducing it into this Paper.

It is simply this: since by knowing the radii of curvature of a lens, and its index of refraction, we may compute the focal length; so, conversely, by knowing the radii and measuring the focal length, we may compute the index of refraction. The method which we employed for measuring the focal length of a lens was as follows: a tube about two inches and a half in diameter, and which exactly measured ten inches from the back of the lens to its other extremity, was fitted with a draw tube of the same length, graduated to inches and tenths; and which, by means of a vernier, might be read to the hundredth of an inch. This was fitted with a positive eye-piece, which was adjustable to bring the cross wires exactly into its focus, and the graduations above mentioned commenced from this point or stop. A board about two feet square, covered with black crape, and having a clean circular piece of card

paper, with fine cross lines upon it, was placed at a convenient measured distance from the lens, and then the draw tube was adjusted till we had the focus exactly coincident with the cross wires. This is easily ascertained by moving the eye a very little upwards and downwards. Then, when the image does *not* fall on the wires, this motion of the eye will produce an apparent motion between the cross wires in the telescope and those on the card; but when they are coincident, then, however the eye may be moved, the image and the cross wires will be at rest. This being determined, the focal length for this distance of the object is read off as above described. Let this be f , the distance d , radii r, r' , and index $1 + a$; then, by a simple inversion of the well-known formula for the focal length of a lens, we have

$$a = \frac{r r'}{r + r'} \left(\frac{1}{f} + \frac{1}{d} \right).$$

But as for these experimental purposes we made the radii equal, or $r = r'$, this formula becomes simply in this case

$$a = \frac{r}{2} \left(\frac{1}{f} + \frac{1}{d} \right) \dots \dots \dots (1.)$$

Phil. Trans. 1827.

It may be well to describe in this place the method of measuring the tool which is requisite in this proceeding. The lens for this purpose being convex, the tool is necessarily convex. A piece of thin glass was brought on its edge to this curvature nearly by cutting it with the usual shears, or by other means; it was then ground on its edge in the tool till it took the exact curve. The question then is, from this short segmental arc of a circle of 10, 20, &c. to 100 and 200 inches radius, to determine what that radius is. To effect this the segment was laid flat on a long plain board or table, and while held down three pins were pricked in the board to touch the curve, one at each end, and the other in the middle. One end pin was then removed, the glass gauge slipped on in contact with the other two, till one of these was near the end, the pin just removed was then stuck in, the second pin removed, the glass slipped on again, and the last pin again inserted, till the arc of the circle, which on the gauge was only three or four inches, was lengthened ten, twelve, or more times; then, by carefully measuring the subtending chord and versed sine, the radius of curvature was obtained to the greatest accuracy. As an example of the application of the formula given above, let us suppose that the small lens used in the index instrument was exactly 10 inches, that the distance of the object from the lens was 200 inches, and the measured focal length was 11 inches; then, by the formula,

Method of
measuring
the tools.

$$\begin{aligned} a &= \frac{10}{2} \times \left(\frac{1}{11} + \frac{1}{200} \right) \\ \frac{1}{11} &= \cdot 0909 \\ \frac{1}{200} &= \cdot 0050 \\ &\quad \cdot 0959 \\ \frac{10}{2} &= 5 \\ a &= \cdot 4795 \text{ index.}^* \end{aligned}$$

* The proper index is $1 + a$, but we shall in what follows call this decimal part only the index, according to common usage.

Manufactures.

As another example, let the focal length be 10·5, and distance of object 200 inches as before.

Then

$$a = \frac{10}{2} \times \left(\frac{1}{10 \cdot 5} + \frac{1}{200} \right)$$

$$\frac{1}{10 \cdot 5} = \cdot 0952$$

$$\frac{1}{200} = \cdot 0050$$

$$\cdot 1002$$

$$\frac{10}{2} = \frac{5}{1}$$

$$a = \cdot 5010 \text{ index.}$$

Nothing can be desired more simple than this calculation, nor does any practice require a more exact method of determination.

Method of finding the dispersive ratio.

(1105.) *Practical method of finding the dispersive ratio between two pieces of glass.*—The following method of determining the dispersive ratio was first proposed by Mr. Barlow, in the article above referred to; but, in a note, the author states that a similar principle was suggested, but not at that time published, by Sir John Herschel for correcting any slight defect of colour. The views are dissimilar and independent of each other, and the resulting equations are also different but equivalent.

The instrument employed for this purpose is similar to that above described for determining the index, except that the tube, instead of being only 10 inches in length, consists of three joints, one 20 inches, and two others 10 inches each, the draw tube being about 14 inches long, (graduated as before;) so that the length may be conveniently varied between 20 and 50 inches. The cell, which carries one of the lenses at the extremity of this tube, screws inside flush with the tube itself, and will thus admit another tube about 20 inches long to slide over it; at the extremity of the latter is another cell for carrying the plate lens.

This exterior tube is moved over the other by means of a tangent screw and handle, with Hook's universal joint, as in the adjustment of transit and other instruments. Moreover, the exterior tube being opened for the space of two inches, and the interior tube graduated, the distance of the two lenses from each other may always be read off to the hundredth of an inch.

The instrument being thus described, the method of using it, and the principle on which the determination rests, will be readily understood. It is well known that in order to produce achromatism in an object glass, it is requisite that the focal lengths of the two lenses be to each other in the ratio of their dispersive powers; that is, the ratio of the dispersive power of the flint being to that of the plate as 1 : d , the focal length of the flint must be to that of the plate also as 1 : d , the two lenses being in contact.

If, therefore, we have two lenses, viz. a concave flint and a convex plate, in which the focal length of the latter bears a greater ratio to that of the former than 1 to d , we must open the two lenses from each other till the required ratio is obtained, when the object will be colourless, and therefore conversely, when the image is colourless, we shall be sure that the ratio of the focal lengths will be that also of the dispersive powers.

To illustrate this a little more particularly, let f, f' be the focal lengths of the plate and flint lens, and let δ be the distance of the lenses when the image is colourless.

Then, first, it is obvious, that the effect will be the same as if we had a plate lens in contact with the flint, which had for its focal length $f - \delta$, but the actual quantity of its dispersion that due to the whole focal length f ; that is, the same as a plate lens of focal length $f - \delta$,

and whose dispersive power = $\frac{fd}{f - \delta}$.

And since in this state the image is colourless, it follows that

$$f' : f - \delta :: 1 : \frac{fd}{f - \delta}.$$

And therefore d , which is the quantity sought, is found from the equation

$$d = \frac{(f - \delta)^2}{ff'} \dots \dots \dots (2.)$$

The lenses employed were about 2½ inches in diameter, equally convex in the plate, and plano-concave in the flint; their focal lengths varying in the plate and crown from 9½ to 10½ inches, according to their respective refractive indices, and in the flint from about 10 to 11½ inches.

The flint lens, as will have been observed from the preceding description, is placed in the interior tube, and the plate in the exterior; and if, when the two interior faces of the lenses are in contact, the index does not read zero, its actual reading is recorded; and ultimately, the index reading when the image is colourless is corrected by this quantity.

This preliminary being attended to, the manner of conducting the experiments is as follows.

Fix up the black board with the circular white spot, as already described, at a convenient distance, and in a good light, directly opposite the tube properly mounted on its stand.

Let the two lenses be placed nearly in contact, and suppose the length of the tube reduced to about 20 inches. Now move the plate lens gently forward by means of the handle and screw, the eye being placed at the eye-glass, and the image of the circular spot will, after a time, begin to appear in the field of the telescope, having a bright and strong violet spot in the middle; at this time a very little further motion in the plate lens will give a distinct image of the object, but encircled by a strong violet shade.

If now the tube be lengthened to about 25 inches, and the experiment repeated by closing the glasses, the violet spot in the middle, and the circular ring when the focus is obtained, will have changed to a fine blue. If again we lengthen the tube considerably, that is to nearly 50 inches, we shall find by repeating the experiment, that is, by closing still more the two glasses, that the circular spot before the image is formed, and the surrounding atmosphere when the focus is obtained, will be red, orange, or yellow; and between these extremes a focal length will be found where the circular spot in the middle will lose all distinguishing colour, showing itself a bright white, and when in the focus the image will be colourless, although surrounded by a visible atmosphere, principally proceeding from a want of spherical correction.

At this time the glasses are corrected for dispersion, and the compound focal length measured from the back of the flint, and the distance of the glasses must be accurately read off; and with these data the dispersion may be obtained by the formulæ already given, viz. :

Mechanical Processes.

Manufactures.

$$d = \frac{(f - \delta)^2}{ff'}$$

In this expression f is the focal length of the plate lens for the given object, and f' the focal length of the flint for parallel rays. The former may be found by direct observation with the index instrument, as already described, but the latter is best determined by means of the compound focus; that is, calling the compound focus f'' , we shall have

$$\frac{1}{f'} = \frac{1}{f''} - \frac{1}{f - \delta};$$

and f' being thus determined is to be employed in the preceding formula.

As an example: suppose the compound focus measured from the flint to be 34.89 inches, the focal length of the crown lens 9.85 inches, and the distance between the lenses 1.41 inch.

First,
$$\frac{1}{f'} = \frac{1}{38.89} - \frac{1}{8.44};$$

whence
$$f' = 11.13 \text{ inches};$$

then
$$d = \frac{(f - \delta)^2}{ff'} = \frac{8.44^2}{9.85 \times 11.13} = .649,$$

the dispersive ratio sought.

Formulae for computing the curves.

The index of refraction of the plate and flint glass being thus determined and denoted by a and a' respectively, and the dispersive ratio by d , the proposed focal length of the telescope by f'' , then all the other conditions may be computed as follows:

$$f = f'' (1 - d) = \text{focal length of plate.}$$

$$f' = f'' \left(\frac{1 - d}{d} \right) = \text{focal length of flint.}$$

Assume $1 : q'$ to represent the ratio of the radii of the flint surfaces which may be taken at pleasure, (at least within practical limits,) then

$$\begin{aligned} r'' &= f' a' \left(\frac{1 + q'}{q'} \right) = \text{inside radius} \\ r''' &= f' a' (1 + q') = \text{outside ditto,} \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{flint lens.}$$

Find
$$b = \frac{a'}{a + 1}; c' = \frac{(a' + 1)f'' q'}{a' f'' - r''}$$

$$p = \frac{(c' + 1)^2}{(b c' + 1)^2} \times \frac{c' + 2 - b}{c'} \times \frac{a d q'}{q' + 1}.$$

Enter the following Table with this value of p , or the nearest to it, and take out the corresponding value of q :

p .	q .	p .	q .	p .	q .	p .	q .
1.15	.374	1.40	.683	1.65	.972	1.90	1.29
1.20	.446	1.45	.739	1.70	1.03	1.95	1.36
1.25	.506	1.50	.798	1.75	1.09	2.00	1.43
1.30	.568	1.55	.855	1.80	1.16	2.05	1.50
1.35	.625	1.60	.913	1.85	1.22	2.10	1.58

Then
$$\begin{aligned} r &= f a (q + 1) = \text{radius 1st surface} \\ r' &= f a \left(\frac{q + 1}{q} \right) = \text{radius 2d surface} \end{aligned} \quad \left. \begin{array}{l} \\ \end{array} \right\} \text{plate lens.}$$

As we are aware that many practical opticians, as well as some amateurs, feel considerable distaste for algebraical formulæ, we will endeavour to illustrate the rules as above expressed by an example at length.

Let it be proposed to make a refracting telescope 80

inches focus, or $f'' = 80$; the index of the plate having been found to be $a = .515$, of the flint $a' = .600$; the dispersive ratio $d = .66$; and let us choose the ratio $1 : 10$ or $q = 10$, for that of the radii of the curvatures of the flint lens.

Then the first two formulæ in words are as follows:

1. Subtract the dispersion from unity, and multiply the remainder by the proposed focal length of the telescope; the quotient will be the value of f , or focal length of the plate lens.

$$\begin{array}{r} 1.00 \\ .66 \\ \hline .34 \\ 80 \end{array}$$

$f = 27.20$ the focal length of plate.

2. Divide this by the dispersion, and the quotient will be the focal length of the flint, or

$$f' = \frac{27.20}{.66} = 41.21 \text{ inches}$$

To find the radii of the flint surfaces.

3. Multiply the index of the flint by the focal length of the flint lens, and that product by 11, viz. $(q + 1)$; this gives

$$r''' = 6 \times 41.21 \times 11 = 271.9 \text{ outside curve of flint.}$$

$$r'' = \frac{271.9}{10} = 27.19 \text{ inside curve of flint.}$$

We have now determined all except the radii of the plate lens; and the steps here are rather more complicated: we will, however, endeavour to give them in words, viz.

1. Divide the index of the flint by the index plus 1, and call the quotient b . In our case, therefore,

$$b = \frac{.6}{1.6} = .375.$$

2. Multiply the index of the flint plus 1 by the focal length of the telescope, and again by the ratio q ($= 10$) of the flint surfaces, and divide the number thus obtained by the following divisor, viz., From the product of the flint index into length of telescopic focus subtract* the outside radius of the flint; call the quotient c' ; that is, in our example,

$$\begin{array}{r} a' + 1 = 1.6 \\ f'' = 80 \\ \hline 128.0 \\ q = 10 \\ \hline 1280 \text{ dividend.} \end{array}$$

$$\begin{array}{r} a' = .6 \\ f'' = 80 \\ \hline 48 \\ r''' = 271.9 \\ \hline 319.9 \text{ divisor.} \end{array}$$

$$c' = \frac{1280}{319.9} = 4.$$

Lastly. Divide $c' + 1$ by $b c' + 1$, and square the quotient.

Divide c plus 2 minus b by c' .

Divide the product of a (the plate index), d (the dispersion), and q' (the ratio $= 10$), by $q' + 1 = 11$.

* The quantity being negative, the subtraction becomes essentially addition in this example.

Manufac-
tures.

Then these three quotients multiplied together give the value of p .

$$\text{Here } \left(\frac{c' + 1}{b c' + 1} \right)^2 = \frac{25}{6 \cdot 25} = 4 \cdot 0$$

$$\frac{c' + 2 - b}{c'} = \frac{5 \cdot 625}{4 \cdot 0} = 1 \cdot 4$$

$$\frac{a d q'}{q' + 1} = \frac{3 \cdot 393}{11} = 8 = 3 \cdot 1 \text{ nearly.}$$

$$\text{Then } p = 4 \cdot 0 \times 1 \cdot 4 \times 3 \cdot 1 = 1 \cdot 75.$$

The nearest corresponding value in the Table of $q = 1 \cdot 09$. Multiply now q plus 1 by the focal length f and index a of the plate for the front radius of the plate lens, and then that product by $q = \cdot 972$, for the radius of the second surface.

$$\begin{array}{r} \text{That is } q + 1 = 2 \cdot 09 \\ a = \cdot 515 \\ \hline 1045 \\ 209 \\ \hline 1045 \\ 1 \cdot 07635 \\ 27 \cdot 2 \\ \hline 215270 \\ 753445 \\ \hline 215270 \text{ inches radius front surface.} \\ 29 \cdot 27 \end{array}$$

$$\text{And } \frac{29 \cdot 2}{1 \cdot 09} = 27 \text{ inches radius second surface.}$$

We have thus all the curves proper for a telescope of 80 inches focus, with glass of the indices and dispersive ratio above stated.

Plate lens	front surface	271 \cdot 9	convex.
	second surface	27 \cdot 19	convex.
Flint lens	contact surface	27 \cdot 61	concave.
	back surface	28 \cdot 4	concave.

Grinding,
polishing.

(1106.) *Practical operations of grinding.*—The requisite curves being thus determined, tools must be provided of the same curvatures, but reversedly, that is, a concave tool for the convex surface, and a convex for the concave. These tools are made of brass, about an inch or an inch and a half thick, and eight, ten, or twelve inches in diameter, with a piece left at the back, in which a coarse thread can be tapped for the purpose of fixing them to work the glass. Each tool ought to have its fellow, so that by grinding the two together the most perfect spherical figure may be obtained. Two pieces of brass, of the thickness above stated, are cast to wooden patterns nearly of the curvature required; they are then, by means of the screw, tapped in the piece at the back, attached to the mandril of a lathe, brought to a good surface, and to nearly the proper curvature. The two, that is, the convex and concave tool, are now worked together with coarse emery till the two surfaces touch each other in all parts, in all positions, when they must necessarily be both perfectly spherical, for no other curve surfaces possess this property of universal contact.

In the workshop is a cast-iron pedestal about three feet and a half high, at the top of which there is a screw, and upon this the tool is secured by the thread tapped in the piece of brass left at its back, and is thus in a condition to commence the grinding. The piece of glass to be ground, being first cut roughly round by the diamond and a pair of optician's shears, is to be fixed

on a handle by means of pitch, that is, the pitch is made sufficiently warm to be quite plastic; it is then attached to the handle, and the glass laid on and compressed, and moved by the hand till it becomes central; when cool, the pitch will have a strong attachment to both. A quantity of coarse emery and water is now smeared over the surface of the tool, and the glass worked in it till all the outside part (if a concave lens) is ground away so that the lens has taken up the required spherical figure. A finer emery is now employed, and greater caution observed to improve the first rough surface; then again a still finer sort, till at length the most complete contact is obtained between the glass and the tool in all and every part of the surface.

The next step is the polishing, which requires the utmost care, not only to get the polish perfect, but also to avoid in this process destroying the figure given by the last. For this operation all the emery is washed out of the tool, and a piece of thin felt or cloth is spread on its surface, and on this a quantity of polishing putty. The workman then proceeds as in grinding, but using great precaution with respect to the degree of pressure he gives, and after some hours' work a perfectly polished spherical surface will be obtained. This being done, the workman by a smart blow, dexterously applied at the back of the glass, disengages it from the pitch on the handle; he then again warms the pitch and attaches the polished side, and works over the other surface on a tool already prepared of proper curvature, and which being ground and polished in the same way, the lens is again removed from the handle, and is thus far finished.

The next step is what is called centring. We will suppose the lens to be convex on both sides; the centring is to give to the lens such a figure that the axes of the two spheres, of which the surfaces are segments, shall be in the same right line; for this continuation of the two axes is supposed in the calculation for curvatures, and upon the perfect centricity of the lenses much of the beauty of the performance of the telescope depends. The centring is effected by attaching the lens by means of pitch and a chuck to the mandril of a lathe, and while the pitch is still warm enough to be pliable, the position of the lens is changed by a pressure of the hand, till, by revolving the mandril as in turning, any object seen through the edges of the lens, or any object seen by reflection on its outer surface, remains steady to the eye during the revolutions. If this is not the case at first, the workman by practice judges what is wanted, and he either lowers or raises the lens on the pitch, or inclines it a little more or less, till by repeated trials the objects seen, both by reflection and refraction, remain stationary during the rapid revolution of the lathe; he then concludes that the lens is fixed centrally, that is, that the two axes coincide, and it only remains to cut it down to a perfect circle.

To effect this, the lens is left on the mandril till the pitch is quite hard. A man or boy now turns the lathe with his foot very rapidly, and being provided with a sort of tin pan and plenty of coarse emery, he applies this at a fixed distance from the centre of the lens, so that the parts most distant from the centre rub pretty strongly against it; by this means these prominent parts are soon reduced. He then approaches his tool a little more, and thus reaches the next projecting parts of the circumference, and so on till he has ground the rest of the prominent parts down, and produced a most perfect circle, which must, when the lens is properly cen-

Mechanical
Processes.

Polishing.

Centring.

Manufac-
tures.

tred, be of equal thickness all round. The lens is now finished, and is washed with spirit of wine, &c. to remove any remnants of pitch, and carefully laid aside till wanted. Precisely the same process is followed with the other lens, but this being concave is of course worked on a convex tool; in every other respect the operation is the same. Both being finished and reduced to exactly the same diameter, their proper surfaces are placed together, and are in this form introduced and secured in a brass cell made to receive them, the size of which must be such as, while it prevents any motion between the two glasses, must not be so tight as to pinch them in any respect, for the least pressure produces a flexure in the lens and totally destroys that accuracy of performance so essential in refracting telescopes, particularly those employed for astronomical purposes.

Grinding
lenses by
machinery.
Pl. lxxxiv.
Fig. 1, 2.

(1107.) *Grinding and polishing by machinery.*—Our best opticians never think of applying machinery for grinding the lenses of the larger and finer telescopes, though we are much inclined to believe that it might be done to advantage; but for grinding common magnifying lenses, such as spectacle glasses, and those for common pocket telescopes, &c., a horse mill is sometimes employed, and some hundreds of spectacle glasses all ground at once. Mr. William Gilbert, 148, Leadenhall-street, had a mill of this sort in his manufactory at Woodford, in which four hundred or more spectacle glasses might be ground at the same time. In these cases the tools are made rather broader than for common hand grinding, and thirty, forty, or even seventy small lenses, or pieces of glass which are to be lenses, are fixed by pitch side by side over the whole surface of one tool, and this tool thus filled is placed on the top of a fixed axle, or to one to which a circular motion is given by the mill, and twenty or more such axles may be revolving at the same time. If we suppose these to be for convex glasses, they must of course be placed on a convex tool, and over them is laid a proper concave tool, the centre of which is attached freely and eccentrically by a crank to the end of a descending vertical axis, which is also driven by the horse mill in an opposite direction to the former. The mill being now put in motion and emery supplied as in hand grinding, the upper tool is made to roll and revolve over the lower eccentrically, while the lower one itself is revolving centrally with a slow motion, so that every part passes under the upper tool, and all the lenses, after a short time, are found reduced to their proper figure, and are then polished; after which they are turned, and in like manner ground and polished on their other side. The crank to the descending axis is so managed that any one tool may be easily disconnected, and may be made to work more or less eccentrically at pleasure.

The above general description will be better understood by referring to fig. 1, 2, plate lxxxiv. in which one tool is represented as grinding and the other as polishing. The central axle is driven, as we have said, by a horse mill. This axle carries two drums, A, B; G E are two iron axles passing through collars in the frame of the mill as represented in the figure, and are driven by bands passing over the drum and pulleys on the axle. These axles, at their lower end, pass through circular holes in the pieces of metal F, F, in which they turn freely till connected by the locking pin *a b*, *a' b'* with the axle. Thus far both sides agree; but now we have some difference to describe. In fig. 1, an iron bar passes through a block of iron attached to the centre

piece F, which bar is bent at its end into the spring C, of the form shown in the figure. The tool H is screwed on the fixed axle A, passing through a heavy collar K, in which, by means of the strong set screw B this may be elevated or depressed at pleasure. At the further angular end of the spring C is a recess or socket, into which is entered the end of the spindle, represented as screwed into the running tool R, which by this means presses the tool or runner down upon the fixed tool; the proper degree of pressure being adjusted by raising or lowering the axle A, and the proper degree of eccentricity is given to the spring bar by sliding it in its collar, and there fixing it by its set screw S. This pressure is such, however, as allows the workman at any time to raise the spring by his hand, and thereby to remove the tool. The action of the locking bar will be readily understood without any particular description; by a smart blow at *b* with a mallet the connection between the axle and collar is broken, and by a blow at *a* the connection is as readily established.

Mechanical
Processes.

On the other side the tool is represented as polishing, the lenses being cemented upon the lower tool. Here the action of the locking bar is the same as already described; but the bar which in the other figure is bent into the spring form is here terminated by a ring, into which the axle of the running tool is inserted, so that only the weight of the tool acts. The lower tool also, in this case, revolves by means of a strap passing over the lower drum and pulley, but this band being crossed the two axles revolve in opposite directions; they are also placed a little eccentric with regard to each other as represented in the figure.

We have only shown two axles, or two pairs of tools; but the mill consists of a square frame, on three sides of which several such axles as are here represented are working at the same time by the labour of one horse, and requiring only the attendance of one man to grind some hundred glasses. The writer has seen four hundred small lenses under operation at one time. This ingenious piece of mechanism is the invention of Mr. William Gilbert, of the firm of Messrs. Gilbert, opticians and mathematical instrument makers, 148, Leadenhall-street.

(1108.) *Grinding specula for reflecting telescopes.*—As we thought it necessary to preface our description of grinding lenses by the rules necessary for computing the proper curves, so also here it is considered to be requisite to state a few particulars relative to the best composition for speculum metal, and the caution which is required in the casting. The specula of reflecting telescopes are generally composed of thirty-two parts of copper and fifteen of grain tin, with the addition of two parts of arsenic to render the composition more white and compact; but the Rev. Mr. Edwards, in the *Nautical Almanack* for 1797, has detailed a variety of experiments on this subject; he found that adding one part of brass and one of silver to the above composition, and using in it only one part of arsenic, a most excellent metal is obtained, which is the whitest, hardest, and most reflective of any he ever saw. The superiority of this composition has been completely proved by the excellence of the instruments made by this gentleman, which are said to have excelled all others in brightness and distinctness; but, unfortunately, metals of this composition are exceedingly difficult to cast as well as to grind and polish, and for this reason they are not so commonly used as could be desired.

Specula.
Composi-
tion.

The following directions for casting are given by Sir

Casting.

Manufac-
tures.

D. Brewster, in his edition of Ferguson's *Lectures*. After the flasks of sand are prepared, and a mould made for the metal by means of a wooden or metallic pattern so that its face may be downwards, and a few small holes left in the sand at its back for the free egress of the included air, melt the copper in a crucible by itself, and, when it is reduced to a fluid state, fuse the tin in a separate crucible and mix it with the melted copper by stirring them together with a wooden spatula. The proper quantity of powdered arsenic, wrapt up in a piece of paper, is then to be added, the operator holding his breath till the fumes are completely dissipated, and when the scoria is removed from the fluid mass, it should be poured out as quickly as possible from the crucible into the flasks. As soon as the metal is become solid, it should be removed from the sand into some hot ashes and coals for the purpose of annealing it, and where it ought to remain till it is cold. The ingate is then to be removed from the metal by means of a file, and the surface of the speculum ground upon a common grindstone, till all the imperfections and asperities are taken away. When Edwards's composition is employed, the copper and tin should be melted according to the preceding directions, and when mixed together should be poured into cold water, which will separate the mass into a number of small particles, which are then to be collected and put into the crucible with the silver and brass. After they have been melted together in a separate crucible, the proper quantity of arsenic is then to be added, and a little powdered rosin thrown into the fluid metal before it is poured into the flasks.

Difficulties
in casting
large spec-
ula.

For the smaller kind of specula these directions may be successfully followed; but in the larger sort great difficulty is encountered, and unfortunately a more debased metal must be employed. Sir William Herschel, as is well known, cast a speculum for his forty-foot reflector of four feet diameter, the weight of which was nearly half a ton; but in this the proportions of tin and copper were about as one to three. Lord Oxmantown has, perhaps, taken a greater part than any other person besides Sir William Herschel in attempts to produce very large reflectors, and has erected for the purpose not only a proper foundry for casting, but also a steam-engine of four-horse power for grinding them; and some useful remarks are given by this ingenious Nobleman on the subject, in Brewster's *Journal* for 1830, vol. ix. He there remarks, "I will endeavour to put the reader in possession of the difficulties he would have to encounter, were he to proceed to construct a large telescope in the common way, and the defects he would probably find in the instrument when finished. He would of course first proceed to cast the metal, and as earthen vessels would not be sufficiently capacious, he would employ either iron ones or reverberating furnaces. If he tried iron vessels before a large quantity of speculum metal (for instance, three or four hundred weight) was raised to a proper heat for casting, he would find that the metal had imbibed some of the iron and was injured, or perhaps, if he were less fortunate, and the fire had been a little mismanaged, that the speculum metal had promoted the fusion of the iron, and thus passed out through the crucible. The reverberating furnace would then be resorted to, and much difficulty would occur in combating the continual change of the quality of the metal from the exposure of so large a surface to the action of the flame. However, the metal once cast, the next process is to anneal it; and he would then find

the speculum would fly to pieces before it was cool, unless the alloy made use of was less bright, less white, and in every respect inferior to the best speculum metal. The next process is to grind the speculum, which, though laborious, does not require much exactness; and, lastly, to polish it, which every one knows is attended with great difficulty. Making a proper estimate of the success likely to be obtained after a great number of abortive attempts, a metal would be completed having a tinge of yellow, deeper in proportion to its size, with perhaps a defective polish, and certainly a figure by no means perfect." Such are the difficulties which attend the casting and completing a large reflecting speculum, and to avoid some of them an inferior metal is had recourse to. Dr. Pearson, in his *Practical Astronomy*, states, that the proportion of tin to copper used by Sir William Herschel for his twenty-foot telescope, was tin 7.75 copper 20, an alloy certainly extremely low, and the metal of the forty-foot was still lower. The defects, therefore, Lord Oxmantown observes, common to all very large specula hitherto constructed may be thus stated: a defective metallic composition ill suited either to receive or retain a polish, or to show objects of their proper colour and brilliancy; a want of sufficient stiffness in proportion to their weight to enable them to retain their figure with that great degree of exactness necessary; and, lastly, a want of as perfect a polish and figure as has been given to smaller specula. The author then proceeds to describe the means he had recourse to in order to obviate these difficulties, which consisted of making the specula with back ribs and flanches, of plating copper with pieces of speculum metal soldered upon them by tin, &c.; but as the description would extend to too great a length, and the completion is not given, we must be content to refer those who are desirous of understanding the process for telescopes of the large size to the Paper in question, and shall proceed to explain the steps necessary to be followed in grinding and polishing metals of a more common size.

(1109.) *Grinding by hand.*—The metal being cast and prepared by the common grindstone for receiving its proper figure, the gauges and grinding tools are to be formed in the same manner as for lenses, as already described, the radius of the gauges being always twice that of the intended focal length of the speculum. In addition to the convex and concave brass tools, which should be only a little broader than the metal itself, a convex elliptical tool of lead and tin should also be formed with the same radius, so that its transverse may be to its conjugate diameter as ten to nine, the latter being exactly equal to the diameter of the metal; on this tool the speculum is to be ground with flour emery in the same manner as lenses, with circular and cross strokes alternately, till the surface is freed from every imperfection and has taken the true spherical figure. It is then to be worked with great care on the convex brass tool with emery of different degrees of fineness, the concave tool being sometimes ground on the convex to keep them to a proper radius, and, when every scratch and appearance of roughness is removed from the surface, it will be fit for receiving the final polish.

Before the speculum is brought to the polishing tool, it has been the practice to smooth it on a bed of hones, covered with a number of grooves at right angles to each other, and about the thirtieth of an inch broad and deep. This additional tool is indeed absolutely necessary when silver and brass enter into the composition

Mechanical
Processes.

Grinding
and polish-
ing by
hand.

Polishing
specula.

Manufac-
tures.

of the metal, in order to remove the roughness which will always remain after the finest emery has been used; but when these metals are not ingredients in the speculum, there is no occasion for the bed of hones; and Sir D. Brewster observes, in his edition of Ferguson's *Lectures*, that he has attained as fine a polish as it is possible to have without the intervention of this tool. Mr. Edwards does not employ any brass tool in his process; but transfers the metal from the elliptical leaden tool at once to the bed of hones, which certainly simplifies the process; but there is some doubt in Sir D. Brewster's mind if any improvement is thus effected. As a bed of hones is more likely to change its form than a tool of brass, it is certainly of great consequence that the speculum should have as true a figure as possible before it is brought to the hones; and this figure may certainly be better obtained on a brass tool, which can always be kept to its figure by its pair tool, than an elliptical block of lead, and we are certain that, when the focal length is to be very exactly of a given length, the brass tool is the most certain. Mr. Edwards, however, states that these tools are not only unnecessary but detrimental; in which opinion, however, Sir D. Brewster does not coincide. He observes, "That Mr. Edwards found them unnecessary, we cannot doubt, from the excellence of the specula he formed without their assistance; but it is inconceivable how the tool can be in the least detrimental. If the mirror is ground upon twenty different tools before it is brought to the bed of hones, it will receive from the last of these tools a certain figure which it would have received even if it had not been ground upon any of the rest; and it cannot be questioned that a metal wrought upon a pair of brass tools is equally, if not more, fit for the bed of hones than if it had been merely ground on a bed of hones."

When the metal is ready for polishing, the elliptical leaden tool is to be covered with black pitch about one-twentieth of an inch thick, hardened a little in the warmer weather with a little rosin, and the polisher formed either with the brass tool, or with the metal itself. The colcothar of vitriol should then be triturated between two surfaces of glass, and a considerable quantity of it applied at first to the surface of the polisher. The speculum is then to be worked in the usual way upon the polishing tool till it has received a brilliant lustre, taking care to use no more of the colcothar if it can be avoided, and at all events the least possible quantity of it after the first. When the metal moves stiffly on the polisher, and the colcothar assumes a dark muddy hue, the polish advances with great rapidity, the tool then grows warm, and would probably stick to the speculum if the motion were discontinued for a moment. At this stage of the process, therefore, it is necessary to proceed with great caution, breathing continually on the polisher till the friction is so great as to retard the motion of the speculum. When this happens, the speculum is to be slipped off the tool at one side, cleaned with soft leather, and placed in a tube for the purpose of trying its performance, and if the polishing has been conducted with care, it will be found to have its true figure.

In polishing the small speculum for his Newtonian reflectors, Sir W. Herschel always employed two or more tools considerably larger than the speculum to be polished, but he did not use them till after the speculum was made nearly flat with emery upon a small tool of lead. These tools or beds of hones should not

VOL. VIII.

be less than six inches in diameter, and they are not to be considered as completed till the speculum can be first highly finished upon one of them, and afterwards be applied to another without experiencing any change of figure. The last six strokes should be performed in the direction of the longer axis of the ellipse; when the speculum is thus brought to a perfect figure, it must be polished upon a pitch polisher of a circular form, whose diameter is but one-tenth greater than the transverse axis of the speculum. Ferguson's *Lectures* by Brewster.

(1110.) *Grinding specula by machinery*.—Several different means have been devised for grinding and polishing specula by machinery, but our limits will not admit of our entering upon them at great length. A machine for this purpose, on a very large scale, has been constructed under the direction of Lord Oxmantown, which is worked by a four-horse power steam-engine, the operation of which is exceedingly simple. A drawing and description of this machine is given by this ingenious Nobleman in vol. ix., of the *Edinburgh Journal of Science*; but as it is calculated only, or principally, for the larger specula, viz., those of two, three, or four feet diameter, it is not likely to be called for by the generality of experimenters on this subject: we therefore will merely refer such readers as are desirous of understanding its operation to the Work quoted above, and shall devote the remainder of this article to a machine on a smaller scale, lately presented to the Society of Arts by Dr. Green, of Cork, which is applicable to specula of a medium size, but is, perhaps, rather more complicated than is necessary.

This machine is represented in plate lxxxiv. fig. 3, 4, &c. The length of the frame *a b* is 5 feet; the two long bars *c, d* are $2\frac{1}{2}$ inches broad by $3\frac{1}{2}$ inches deep, and are 9 inches asunder on the outside; the machine stands upon four legs, $2\frac{1}{2}$ inches square, which raise the upper face of the bars 15 inches high. The cross piece *a*, through which the mandril *e* passes, is 2 feet 8 inches long, $4\frac{1}{2}$ inches wide, and $2\frac{1}{2}$ deep; the cross bar *b*, at the other end, is 20 inches long, $3\frac{1}{2}$ wide, and $2\frac{1}{2}$ deep. The square front *f f*, which carries the pillar *g*, is 12 inches square and $1\frac{1}{2}$ thick, and is firmly fixed by seven screws to the upper surface of the cross piece *a* and of one of the long bars, as is plainly seen in the figure. This board covers one part of the bar and part of the cross piece *a* to their edges; it stands $1\frac{1}{2}$ inch above the edge of the frame, and firmly binds the long bar *d* to the cross piece *a*. The legs are firmly mortised into cross pieces at the bottom, $2\frac{1}{2}$ inches wide and $1\frac{1}{2}$ thick. The mandril is 14 inches long, $1\frac{1}{2}$ diameter at its shoulder, tapering gradually to two-fourths of an inch at the lower end, in which there is a small hole drilled to rest upon a pointed screw of hard steel *h*, which is attached to the lower cross piece. The upper part of the mandril works in a bell-metal collar, let into the upper cross piece *a*, and on a level with its upper surface: the mandril is to be ground into this collar until its shoulder shall stand only one-quarter of an inch above the surface of the frame: the mandril must stand truly perpendicular, and at the distance of about 1 inch from the leg of the machine. The screw of the mandril may be about three-fourths of an inch in diameter, and as much in length. The bell crank *i* has each arm 9 inches from the centre of motion to the joints of the connecting rods *j*; it works upon a steel arbor, which passes through the pillar *g*, which is to be firmly fixed near one corner of the square board *f*.

Mechanical
Processes.

Machine
for grind-
ing specula.

Lord Ox-
mantown's
machine for
large spe-
cula.

Dr. Green's
machine.
Pl. lxxxiv.
Fig. 3, 4, &c.

Manufac-
tures.

This pillar is $2\frac{1}{2}$ inches high; the crank is secured by a nut, and is to be ground on the arbor so as to have a very smooth and steady motion. The double joints of the connecting rods *j* and *k* are each formed of one piece of metal as represented, one cut receiving the ends of the arm of the bell crank *i*, while the other cut receives a steel plate *l*, which is riveted into the end of the connecting rod *k*; this forms a steady universal joint when steel pins are put into the holes. The fly wheel *m* is 26 inches diameter, and weighs from forty to fifty pounds. The screw upon the end of the mandril is destined to receive a disc or chuck of cast iron, 7 inches diameter, 1 inch in thickness at the centre, and gradually decreasing to half an inch at the edge, having its upper surface quite flat. Upon the flat surface of this chuck the pewter polishing tool is fixed with six common $1\frac{1}{4}$ inch screws which pass through the chuck, in which there are six holes near the margin, and screw into the pewter. The margin of the pewter polisher is elliptical, 10 inches by 9, and $1\frac{1}{2}$ thick. Between the chuck and the polisher a circular disc of sheet lead *n*, 15 inches diameter, is to be interposed; its edge is to be turned up into the form *n*, exactly resembling a common fryingpan, about 1 inch deep, and 12 to 13 inches diameter; it is to retain the mud that is formed in grinding or polishing, and it thus keeps every thing clean. To the under surface of the chuck a brass ring, 7 inches diameter outside, $5\frac{1}{2}$ inside, and three-eighths thick, is to be fastened to six screws; and when on the chuck, and the chuck on the mandril, its edge is to be turned with a groove like a pulley, in which a screw of about ten threads to the inch is to be cut. The face of the pewter polisher is also to be turned to the degree of convexity required after it is affixed to the chuck. An endless screw *o* runs in this pulley, and gives a slow rotation to the chuck and its polisher. This screw is of steel hardened and tempered, and by notching three or four threads at its end like a tap it will cut the pulley in its place; when it is cut, by moving the bearing in which the other end of the screw runs about an inch nearer, the pulley will cause it to revolve. The screw receives its motion from a pulley *p*, 4 inches diameter, fixed upon its axis or shank, and a band which also passes over the small pulley *q*, of 2 inches diameter, upon the axis of the fly. The fly is moved by the pulley *r*, 4 inches diameter, which corresponds with the wheel *s*, 12 inches diameter, on the axis of which is the winch handle *t*, which gives motion to the machine. This same axis has a second pulley *v*, 12 inches diameter, and upon its axis are two other pulleys, *w* $9\frac{3}{4}$, and *x* $7\frac{1}{2}$ inches diameter. The axis of these three pulleys is raised 4 inches above the level of the frame by two solid blocks; one, *y*, only is seen. One of the legs *z* of the frame is longer than the others, and projects six inches above its upper surface. A groove is to be cut in its top to allow another axis *I* to rest in it 5 inches above the frame; this axis is supported horizontally by a pillar 2, in the model; but it would be more simple to make the other leg as long as the leg *z*. On this axis are two pulleys, 3, 9 inches diameter opposite to *w* and 4, $11\frac{1}{4}$ diameter opposite to *x*, so that the same band can be passed from one pair of pulleys to the other pair in an instant, without making any alteration in its length.

The pulleys are all formed of three pieces, to prevent warping, viz. a three-quarter-inch plank in the middle, having a three-eighth plank glued on each side of it with

the grain of the two latter at right angles to that of the former. When dry, let them be wedged with glue upon that part of their axes where they are to remain, and let them be turned on their axes with their edges a little convex, which form has the property of preventing the band from slipping off. A strip of woollen cloth glued on the edge of the pulleys will increase the adhesion and allow them to work with looser bands. The axes are formed of three-quarter-inch square bars of scrap iron, and require no forging; the bands may be made of buff strap, or of such leather as the saddlers employ for stirrup leathers, and should be fully an inch broad and put on pretty tight. The pulleys 1 and 2 need not be more than an inch in thickness, and their band of one-half inch broad may be left very loose. The pivots of all the axes run in boxes or bearings of box-wood, and are screwed up pretty tight. These are easily made; they give a very smooth motion, little disposed to heat, wear, or dirty the oil, and are far preferable to brass or bell metal.

Upon the projecting extremity of the axis *I*, which carries the pulleys 3, 4, is fixed a strong straight crank 5, shown larger in fig. 4, about six inches long, and graduated on its face to tenths of an inch. On its slide is an iron box or square tube 6, having the outer side 6 projecting so much beyond the other three sides towards the centre of motion that a steel stud 7 affixed to it can be made to slide over the centre of the axis *I*, or be placed at any required distance from it, and be kept in its place by the pressure of the screw 8, which passes through one side of the box and bears upon the crank 5, thus rendering the length of the crank variable at pleasure, and capable of being altered in a few seconds. On the base of this stud 7 is a fast pulley 9, an inch in diameter, and having a deep groove in it; the rotation of this pulley gives motion to the mirror; on this stud hangs the connecting rod 10, 10, fig. 3, which is attached to the back of the mirror. A nearly similar crank 11 is upon the end of the axis which carries the pulleys *v*, *w*, and *x*, but at the opposite side of the machine. The only difference between them is that the sliding box of the crank has no pulley upon its steel stud, which receives the connecting rod *h*, giving motion to the bell crank *i*. The connecting rods are attached to the cranks in the following manner: a hard steel plate of the form 12, fig. 5, is firmly screwed or riveted to the side of the wooden connecting rod 10, next to the crank. The notch of this plate hooks upon the neck of the stud 7, and they should fit each other accurately. The plate 13, which revolves round a screw on the under side of the connecting rod, being pushed under the stud, keeps the plate 12 in its place, and prevents it from unhooking. This is a convenient mode of fastening the rod 10, 10, in particular as it frequently requires to be detached very quickly in the act of polishing.

(1111.) *Motion of the speculum.*—Let a back (as it is called) be prepared of hard pewter, two-thirds the diameter of the speculum, and for a 9-inch mirror fully half an inch in thickness at the centre, and decreasing gradually to one-eighth of an inch at the edge. Let its under surface be turned as nearly as can be to fit the back surface of the mirror. A female screw, $1\frac{1}{2}$ inch diameter, is to be turned in its centre quite through; this back is afterwards to be cemented upon the mirror with soft pitch, and its centre should accurately coincide with the centre of the mirror; a brass handle is to fit into the screw of this pewter back. It is of the form

Mechanical
Processes.

Method of
giving mo-
tion to the
speculum.

Manufac-
tures.

represented in fig. 7: the screw 14, half an inch long and $1\frac{1}{2}$ diameter; the flanch 15, $2\frac{1}{2}$ diameter and one-eighth in thickness; the cylinder 16, $1\frac{1}{2}$ inch diameter and one half long; a square prism 17, the largest that can be formed out of the cylinder, and an inch in height. On the top of it stands a screw 18, half an inch in diameter, and an inch in length. This handle is to be screwed tight into the pewter back before it is struck on the mirror, and a circular disc of thin paper should be pasted on the end of the screw, so as to cover the joint, to prevent the pitch from entering it, which would render the removal of the brass handle a matter of difficulty. The cylinder 16 of the handle receives the rings of two connecting rods 10, 10, and j , and their form is easily understood by referring to fig. 8; a ring of stout sheet brass, 2 inches in width, and nicely fitting upon the cylindrical part of the handle, is represented by 19. A hinge 20, to allow the ring to follow the curvature of the polisher, terminates in two plates of brass 21, 21, which are firmly riveted to the wooden connecting rod 10, 10. The length of the connecting rods must be such that, when the studs of the sliding boxes of the two cranks are placed over the centres of their respective axes, the sides or arms of the bell crank shall be parallel to the sides of the square board on which it stands; and the centres of the two rings of 10, 10, and j , shall both coincide with the centre of the polisher when they are put upon the cylinder of the brass handle, which is screwed into the pewter back attached to the speculum. A washer of fine card should be interposed between the flanches of the handle and the ring next to it, another between the two rings, and a third between the upper ring and the wooden pulley 22, which keeps the rings in their places and gives rotation to the mirror. This pulley should be made of light wood 14 or 15 inches diameter, and three-eighths in thickness at the edge, in which a deep groove is to be cut, but strengthened at the centre by a piece of hard wood, making its centre there fully an inch, gradually tapering off so as to support another 6 inches of its centre. This pulley fits upon the prism of the brass handle, and is fastened down by a circular nut of box-wood, which screws upon the upper or smaller screw of the handle. It is seen in its place in fig. 3, and receives rotation from the first pulley 9, attached to the stud 7 of the variable crank 5, by a gut band 23, 23; 24 is a small guide and tightening pulley, 2 inches diameter, on one end of a flat strip of brass about 6 inches long, the other end of which is fastened by a screw to the upper part of the connecting rod 10, 10. This bar moves stiffly round the screw, and will remain at any angle to which it is set.

Action of
the ma-
chine.

(1112.) *Action of the machine.*—The action of the machine can now be easily understood. If either of the cranks be shortened to nothing by fixing the stud in the centre of motion, the other crank will cause the mirror to move backwards and forwards with cross strokes over the centre of the polisher; while the polisher revolving slowly in one direction, and the mirror in an opposite one, the different parts of each will have their relative positions perpetually changing. The extent of the stroke given by each crank will be double the length of the crank; and this is altered in an instant by sliding the box with the stud upon the crank.

Let us now suppose both sliding cranks set to the same length, and the band passing over the pulleys w and 3, of $9\frac{3}{4}$ and 9 inches diameter, and suppose their

cranks, at any moment of time, to be vertical, and of course at right angles to their connecting rods; now as their motion is so nearly equal, they will remain nearly parallel to each other for one revolution, and their joint action will be to cause the mirror to move in the diagonal of the two forces, and it will describe two cross strokes in nearly a straight line over the centre of the polisher. When, however, the pulley w shall have described three revolutions, the cranks, which were at first parallel, will now be found at right angles to each other. The effect now produced will be, that one crank, at right angles to its connecting rod, will propel it with its greatest velocity, while the other crank, parallel to its connecting rod, gives it scarcely any motion; and the mirror being at this time at its greatest distance from the centre of the polisher, the first crank, acting upon it at right angles as a continually deflecting force, will cause it to describe a curve nearly circular around the centre of the polisher; at every revolution this curve approaches the straight line or transverse stroke over the centre of the polisher, and at the end of three more revolutions of the pulley w it will again give a stroke nearly transverse, which will again gradually change into a curve in the opposite direction. If the band be now passed over the pulleys x and 4, of $7\frac{1}{2}$ and $11\frac{1}{4}$ inches diameter, the changes from curves to a position of a straight stroke succeed each other so rapidly that the path of the mirror will in some degree resemble a capital L in writing, which being frequently repeated will cover the polisher in every direction.

In the above instances we have supposed the two cranks of equal length; but it is obvious that, by varying their proportion to each other, an endless variety of curves can be produced. Were it desirable to polish by circular or elliptical strokes round the centre of the polisher, it could easily be effected by having two more pulleys in the arbors moving the cranks, each being $9\frac{3}{8}$ inches diameter. As the two cranks would now move with equal velocity, by setting them at right angles at starting they would retain their relative position; but if their length were equal, the centre of the mirror would move in a circle around the centre of the polisher; but if the length of the cranks were unequal, its path would be an ellipse.

(1113.) *Path described by the mirror.*—For the use of those who have not had an opportunity of seeing the machine or model in action, Dr. Green has traced a few diagrams, describing the path of the centre of the mirror over the surface of the polisher: "This was effected by fixing a piece of card pasteboard in the place of the polisher, and uniting the two connecting rods upon a piece of tube, which allowed a pencil to pass through it freely yet steadily, and the pencil was loaded with a weight sufficient to cause it to trace. In forming fig. 8 both cranks were fixed parallel to each other, and vertical, which placed the pencil in the centre: one quarter of a revolution of the cranks carried the pencil to 25, which is nearly a straight line. At 25 it turns sharp, and traces the line to 26 somewhat curved, it then returns through another curve, and back again through a line still more curved than any of the preceding, and thus a path may be traced by the lines in the figure. When arrived at the fifth and sixth line, it will be seen that the curves are nearly circular, as the cranks are at this time at right angles to each other; the curves now begin to close in a direction at right angles to the first line, and by the eleventh or twelfth turn of the crank

Mechanical
Processes.

Path of the
mirror.

Manufac-
tures.

become very elliptical, and at last nearly straight; the cranks having again become parallel, the machine was stopped when the pencil came to the centre. The ratio of the diameter of the pulleys moving the cranks was about that of 23 to 24, and the cranks were of equal length: this Dr. Green calls the primitive figure of that ratio.

"Were the machine continued in action for as many more revolutions, a similar figure would be repeated; but not exactly in the same place, except the cranks became parallel precisely at the time of their being horizontal, which is very unlikely to happen.

"As both arms of the bell-crank are equal, the distance 26—27 will be twice the length of one crank, and the distance of 26—28 will be twice the length of the other crank, and those strokes which are nearly circular will have a diameter equal to those lines; but the very elliptical or transverse strokes will be to twice the length of the cranks, as $\frac{3}{2} : 1$, or as the diagonal of a square to one of its sides. This must never be lost sight of in calculating the length of stroke which one may wish to give to the mirror in polishing, as it is well known the length of stroke always commands the figure.

"Similar reasoning is applicable if the cranks be unequal, when one crank is double the length of the other. The lines will be similar to fig. 8, but included in a parallelogram whose sides are as 1 to 2. In this diagram the ratio of the pulleys is also as 23 to 24. These two diagrams were traced with a five-feet machine.

"Those who are practically acquainted with the effects produced upon the figure of mirrors by a difference in the method of working will readily perceive that any of the conic sections which have hitherto been produced by hand-polishing can with this machine be effected with far more certainty and regularity, as it is not possible for the most experienced workman to calculate the length of stroke he employs in polishing by hand. Nor is this all: heat, partially applied, has a surprising influence upon the figure of a mirror; and it is quite impossible to allow for the effect of that which is communicated by the hand when it is directly applied to the mirror, and the unequal pressure of the hand, (which no care can prevent,) I believe, often causes the vertex of the parabola to be found in some part of the mirror different from its centre."

The author gives the following practical hints for the guidance of those who may feel disposed to try polishing with the machine.

Practical
directions.

"In the first place the temper of the pitch is of primary importance, and it should be such that the cross furrows made in it should, at the end of four or five hours' polishing, be diminished in their breadth by about one-third part, and not more, or the pitch will, if so soft, never figure a mirror capable of giving a sharply defined image, although its general figure may appear parabolic, and its polish most exquisite. Secondly, I would advise keeping the polisher always moist, never allowing it to get nearly dry, as is the usual practice with workmen, to obtain a fine polish. This is done to prevent the extreme trouble attending the preparation of a powder of the necessary fineness for wet polishing. To procure such a powder, after long-continued trituration of colcothar or red oxide of iron in a mortar of porcelain or agate, I float off the finer parts with water in the usual manner, returning the coarser into the mortar; I then mix all the fine powder thus washed over in a tall cylindrical jar of thin gum-water; this

will keep the very fine particles suspended for a long time, and allow the heavier to fall to the bottom. The upper portion of the gum-water is then, at a proper time, to be carefully decanted off into another vessel; and, on being further diluted with water, it will, after two or three days, deposit a powder so fine that it may be applied at the last moment, if necessary. Having coated the polisher pretty freely with colcothar washed over with water in the usual manner, I work the mirror an hour and a half or two hours; I then wash it and the mirror well with a flat camel-hair brush and water of the exact temperature of the polisher. I then apply the very fine powder I have described, and wet occasionally with a solution of carbonate of soda, in the proportion of five or six grains to the ounce of water; this removes the harshness of the surface of the pitch without injuring its figure, as an increase of temperature always does. Thirdly, to insure a regular fine figure, it is necessary to alter the length of the cranks whilst the mirror is being polished; this I consider the most important and most essential part of the process. The mirror should be polished partly by very free and bold strokes, partly by very short, and partly by those of an intermediate length. To ascertain how frequently and to what extent these changes should take place is a very complicated subject, of most difficult investigation, and one on which I can at present speak with little confidence; but the relative length of the two cranks I would advise to be always kept between three to two and two to one. Fourthly, the polisher should always be surrounded with a sufficient quantity of water in the leaden pan to cover the bulb of a small thermometer; as pitch is so much affected by a small variation of temperature, that, should any considerable change occur during the process, it is in vain to look for any good result. Fifthly, great attention should be paid to the velocity of the mirror; forty or fifty strokes a minute, if the strokes be long in proportion to the diameter of the mirror, or from fifty to sixty if they are short, is as rapid a motion as ought to be employed; if quicker, it will heat the surface of the pitch and distort the figure of the mirror almost as much as the heat of the hand in hand-polishing, although the error produced will be in the opposite direction.

"Since writing the above description, I have been engaged in assisting my friend Captain H. Kater to get constructed a polishing machine of five feet in length. This gentleman, well known in the philosophical world as a zealous labourer in many departments of Science, the inventor and improver of numerous instruments, has devoted considerable attention to polishing mirrors, and particularly through the medium of machinery. On attentively examining the path of the mirror over the surface of the polisher, which it traverses in every possible direction, it occurred to him that it may not, perhaps, be necessary that the polisher should continually revolve. I fully coincided in his view of the subject, and subsequent experiments have confirmed the correctness of his opinion. This suggestion very considerably simplifies the construction of the machine, and I believe without any injurious effects upon its action. The rotation of the polisher is produced by several parts of the machine, which are by far the most troublesome to execute in its entire construction, and that motion not being necessary, disencumbers it of the following parts: the mandril and its collar; its large iron chuck which carries the polisher; the large brass ring having

Mechanical
Processes.

Proposed
simplifica-
tion of the
machine.

**Manufac-
tures.** a screw cut at its edge, the endless screw *o* with its pulley, the pulley *q* on the axis of the fly-wheel, and their band.

"In place of this apparatus we simply fixed a piece of inch plank one foot square firmly to the frame by four screws, with its centre in that part of the upper cross bar through which it was intended the mandril should pass in case we found it necessary to employ one. Another square piece of plank of the same dimensions was fixed upon the first plank, by one strong screw passing through both their centres, in such a manner that the upper plank can be turned at pleasure by the hand around this screw as an axis, and it moves so stiffly that it will remain in any position in which it is placed, without danger of turning by the action of the mirror. To this upper plank, the polisher and its leaden tray are fixed by four common screws. As the mirror is being polished, this plank is occasionally, that is, every fifteen or twenty minutes, turned round one quarter of a revolution; or the upper board may be turned round, by contact with the tangent screw, as in fig. 3, to keep it moving, its motion being so very slow. A mandril, though perhaps best, is not absolutely required to render that motion smoother.

"The next point for consideration is the mode of attaching the apparatus to the mirror; and this, I may observe, is of the greatest importance towards obtaining a satisfactory result with certainty.

"That many a fine mirror has been destroyed by separating the back is a fact well known to every person who has ever embarked in the delicate and often vexatious operation of figuring specula. If a mirror be bound, pressed, or restrained in any way, by even a very small external force while in the act of being polished, whatever figure it may in that state acquire will be changed to some other curve the moment it is released from that force. So delicately sensible are mirrors, that the slight blow required to detach the back if cold, or the annealing process they must undergo to melt the pitch, if heat be employed, I suspect may suffice to injure an exquisitely fine figure. For this reason I always leave attached to a fine Newtonian mirror the back with which it was polished. To remove this source of error and uncertainty, Captain Kater attached the apparatus to a loose back of strong tin, having a ring round it exactly like the cover of a common round tin canister, the ring being rather less deep than the thickness of the mirror, so as not to touch the pitch. The ring should be so much larger than the mirror that, when lined inside with soft leather, it may not press upon the edge of the mirror in any direction. This method rotates the mirror perfectly well, and the ring will not rise up in polishing if the edge of the mirror be perpendicular to its face. If the mirror be much bevelled at the edge, the apparatus must be cemented to it with pitch; but in this case I would advise a disc of soft and thick buck-skin leather to be interposed between them, taking care that the heat employed to cement them be so moderate as only to soften, not to melt the pitch, so that it may not enter the substance of the leather to harden it, but allow a slight motion between the mirror and the back.

"I am perfectly convinced that a loose cover such as I have described, having the pulleys 9 and 22, and cord-band 23, as in fig. 3, affixed to it, would rotate the mirror as well as the method I have hitherto employed, provided the edge of the mirror be without bevel; and

if in any case a back is to be cemented to a mirror, I would always advise a piece of soft leather to be interposed to prevent any strain between it and the pewter back."—*Trans. Soc. Arts*, vol. 1.

**Mechanical
Processes.**

Manufacture of Biscuits.

(1114.) The great extent of the British Royal Navy, and the still more extraordinary number of merchant vessels daily leaving the different ports of the United Kingdom, necessarily call for a great supply of ship bread or biscuit, the manufacture of which forms a distinct branch of the baking Art, and is in its process exceedingly interesting. While the steam-engine and machinery have been introduced in almost every other Art, that of biscuit-making has, till very lately, been performed by hand. So recently as the year 1833, the first application of these means has been had recourse to for this purpose. The machine is the invention of Mr. Grant, one of the civil officers in his Majesty's Victualling Office at Portsmouth, and is described below; at present our object is to explain the manual process, which, is extremely curious. This process is of course somewhat, but very little, different in its minutiae in different offices; we shall confine our description to that followed in his Majesty's Victualling Office, Deptford. The corn is received from the markets, and is cleaned, ground, and dressed at the splendid corn-mill of that establishment, nearly resembling that already described under the article Flour-mill. The flour used in the manufacture of biscuits for the Royal Navy consists of a mixture of flour and middlings, or it is the flour which remains after the pollard and bran only have been extracted, the corn being highly dried before it is ground. The baking establishment consists of two long buildings, each divided into two baking offices, with six ovens in each, which are ranged back to back along the whole length of the centre of the building; a stone staircase being placed in the middle of the length, by which you first ascend out of one office to the height of the ovens, and down on the other side into the other office, for the convenience of superintendence. The kneading troughs and kneading boards, or breaks, are arranged round the outside walls of the building, one opposite each separate oven. The ovens are all wrought iron, in shape resembling the segment of an ellipse with an area of one hundred and sixty square feet. The furnaces, which are on the sides of the oven, are also of iron, and are heated by a powerful Welsh coal, which gives out a strong flame, and is conducted all round the oven. The number of men required to work each oven is five; these form a gang, and are denominated the *funner*, *funner's mate*, the *driver*, *breaker*, and *idleman*.

**Biscuit-
baking.**

**Biscuit-
baking by
the usual
process.**

Process.—The first operation is that of kneading, in which there is nothing remarkable. The proper quantity of flour is put into a trough, furnished with a cock for a supply of water, and here it is kneaded by the driver with his naked arms till it assumes the rough form of dough. In this state it is removed from the trough and deposited on a strong wooden platform or table, called a *break*, to be operated upon by the breaksman, who, seizes a strong lever called a *break-staff*, with which he presses down the dough, sits with his weight upon it, and, with a rapid jumping and most uncouth motion, carries the lever over the whole surface. It is then transferred to the moulding board, a strong table near

Manufac-
tures.

the mouth of the oven. Here it is cut into slips, and divided into lumps of the proper size for a biscuit. It is then moulded by the hands into its circular shape, laid in pairs one on the other, and subsequently docked, that is pierced with holes by an instrument called a docker; this stamp contains also the number of the oven, D for Deptford, and the usual King's mark. This number and the initial of the yard are specified, in order that, if any defect should be observed in the bread, it may be known where the fault rests. The biscuits, being stamped, are thrown six or eight at a time upon another table nearer to the oven's mouth, where are placed the other three men, one called the *turner*, another the *turner's mate*, and the third the *idleman*, who separates the double biscuit, hands them singly to the turner's mate, who, with great dexterity, and even with elegance, pitches them into the oven upon the peel, handled with equal dexterity by the turner, who places the biscuits as he receives them side by side throughout the whole area of the oven, drawing back his peel a short distance each time to receive the next biscuit. The speed and facility with which this process is carried on are very striking to the eye of a stranger. It of course varies a little, but frequently more than one hundred biscuits are thus pitched in and properly placed in a minute. It may be observed that, with the greatest dexterity, those biscuits first placed in the oven must be most baked; and to equalize this unequal effect the first are made larger than the others, so that the heat may be proportionally distributed; the oven, being filled, is closed for about ten minutes, when it is again opened and the biscuits withdrawn. During the time the oven is closed, and while the bread is being withdrawn, the process of kneading is going forward by the men not employed at the oven, to be ready to commence again as soon as it is empty.

The quantity baked each time, which is called a *suit*, is about 112 pounds weight before being placed in the oven, and which comes out 100 pounds, about 9 per cent. of weight being lost in the process. The number in this weight of biscuit is about five hundred and eighty, that is one with another; there are about six biscuits to a pound. The cost of labour is about one shilling and sixpence per hundred-weight.

The usual number of suits which each oven bakes in a day is twelve, and on extra occasions they can bake sixteen or seventeen; but, even at the usual rate of twelve per day, the twelve ovens will bake 14,400 pounds of biscuit by weight, or about 85,000 by number. It is but justice to those who have the management of this establishment to say, that the order and cleanliness throughout are truly admirable. On a stranger entering the door opposite the middle stone steps or staircase, he is struck with the perfect order and dexterity of the six divisions of the men, each one attired in a clean checked shirt, white linen trowsers, apron, and cap, and all plying their several avocations with a steady rapidity, but without noise or the slightest appearance of hurry or confusion.

Biscuit-
baking by
machinery.

(1115.) *Biscuit-baking by machinery.*—The hand process, such as is above described, had been almost the only means adopted till the year 1833, when a highly ingenious piece of machinery was invented for the purpose by Mr. Grant; and the importance of it will be at once seen when it is stated that, notwithstanding the Government bake-houses at Deptford, Portsmouth, and Plymouth were kept continually at work during the late

war, often with double gangs of workmen, the supply was yet so vastly short of the demand that it was necessary to have recourse to contractors to furnish the additional quantity required; and the wants of the shipping were sometimes so urgent, that bread brought to the Victualling Department in waggons was received in the street and sent off from the spot immediately.

The general superiority of machinery, when applied to a suitable object, over every other species of labour, is peculiarly evident as regards biscuit machinery. The processes on which the goodness of the bread mainly depends, are the thorough kneading of the dough, and its subsequent division into portions of equal size and thickness.

If the meal be not intimately and equally mixed with the water, some portions of the biscuit will be more wet than others, and will consequently require more baking than the dry parts; one of two results must inevitably follow, *i. e.* either the dry parts will become baked, perhaps burnt up, or the moist parts will remain unbaked and become what is usually termed "hard" or "flinty."

The same consequences must attend the division of the dough into biscuits of unequal thickness, or into biscuits of which every part is not equally thick. If the thin biscuits are not over-baked, the thicker must be under-baked, and the thin parts of a badly moulded biscuit will perish from the action of the fire, whilst its thick part is converted into "flint."

The prevalence of "flint" in ship biscuit is well known, though the cause of it has not been so generally understood: its origin, however, is sufficiently obvious, and is neither more nor less than that just pointed out.

The first process in the manufacture of biscuit by machinery is the mixture of the meal and water. The meal is conveyed into a cylinder 3 feet 3 inches in diameter, and the water from a cistern fitted at the back of the cylinder. Through the centre of the cylinder is fitted a rotary shaft, armed with knives, which work in a horizontal position. The spindle being set in motion by engine power, the knives pass through the meal and water: for the first thirty seconds very little amalgamation of the meal and water appears to take place, but after that period the dough commences to assume a consistency, and, in the short space of two minutes from the machine being set in motion, it will produce five hundred-weight of dough completely manufactured.

The cylinder is so fitted that the lower half is easily removed by means of a wheel and pinion from the upper sides, thereby forming a trough containing the new-made dough, from which it is with facility removed and placed under the breaking rollers, to undergo the second operation, that of kneading.

These rollers, two in number, weigh fifteen hundred-weight each, and are propelled by a two-throw crank shaft, by means of connecting rods and pendulum; they pass backwards and forwards over the dough during the space of three minutes, when the five hundred-weight of dough is brought into a solid, perfect, and equal consistency.

From the breaking rollers the dough is cut into pieces eighteen inches square, and placed on boards six feet by three wide, and which are made to pass under other rollers of equal dimensions, and by them rolled to the required thickness of a biscuit; the square of dough being by this operation pressed out so as to cover the surface of the board on which it is conveyed under the

Mechanical
Processes.

Kneading
by ma-
chinery.

Kneading
rollers.

Flattening
rollers.

Manufactures. cutting and stamping plate, which being constructed with mathematical precision, at the same moment cuts and stamps the biscuits complete for the oven, to which they are conveyed on carriages constructed for that purpose.

The machinery thus described requires only eight men and eight boys to supply the nine ovens in the Royal Clarence Victualling Yard, and they manufacture 12,000 biscuits, or one ton of bread per hour, at a cost of 4d. per hundred-weight.

From the quantity of bread that would be required for the Navy in time of war, the saving arising to the Country by the adoption of machinery for the manufacture of it would amount to £12,000 per annum, including a deduction of £10 per cent. on the cost of the machinery for wear and tear.

It is not an unimportant feature in the history of this machinery that furners (the individuals who have the charge of heating, as well as the management of the oven, &c.) are the only tradesmen who will in future be required for the manufacture of machinery biscuit, ordinary labourers and boys being competent to every other part of the work. This advantage can only be fully appreciated by those who had the means of knowing the difficulty experienced in procuring bakers, and the high wages demanded by them, during the late War. The machinery rescues the Government at once from the extortion of bakers hired to work in the public bakehouses, and from all the evils attendant on having recourse to contractors.

The machinery above referred to was first erected at Weovil, near Portsmouth, in 1832, under the direction of Sir John Rennie, and commenced working the following year. It has since been adopted with some modifications by Messrs. Fraser and Hullah, of Wapping, and will, most probably, soon come into more general use.

Mixing machine.
Pl. lxxxv.
Fig. 1, 2, 3. The first machine is the mixer, represented in fig. 1, 2, 3, plate lxxxv. Fig. 2 is an end elevation, fig. 1 a transverse section, and fig. 3 a longitudinal section. It consists of a cast-iron case *a, a*, nearly four feet long and three feet in diameter, enlarged, however, at the upper part, a few inches beyond the circular form, as shown by the upper dotted line in fig. 1. The radial lines in fig. 2 are merely ribs to strengthen the end of the case, opening upwards, to enable the workmen at any time to inspect the interior; and another larger flap or door, *c*, opens downwards, for the purpose of removing the contents of the case. This latter door is opened and shut by means of a quadrant rack *d*, worked by an endless screw *e*, which is moved by a pair of bevel pinions *f*, and these are acted upon by a small winch and axle attached to the supports *g g*. The operation of this machine is as follows: the requisite quantity of flour is sent down from the loft above by the shoot *h*, and the proper quantity of water is supplied from the small cistern *i*, fig. 3, which has a float and gauge, with a line and pulley to indicate the quantity admitted from a larger cistern above, and a pipe and cock to convey the water into the case. The flour and water being admitted, the central axle or shaft *k l* is put into gear with the steam-engine, by means of a coupling box *k*; the axis is thus made to revolve very rapidly, carrying around with it the frame of eighteen knives or mixers *m, m*. These knives, which are curved, as shown in fig. 1, are two inches wide and three-eighths of an inch thick at the back. They are connected at their extremities by similar longitudinal knives, which, in re-

volving, almost touch the lower part of the case. By these means it is evident that the flour and water must, in a short time, become thoroughly mixed. The paste is then removed by hand through the door *c*, and placed upon a table, which is as close as convenient to the mixer, and which is now to be described.

This table is shown in an elevation, fig. 4, plan, fig. 5, Fig. 4, 5, 6, and the transverse section fig. 6. It has a cast-iron frame and legs *a, a, a*, a cast-iron bed *b b*, six feet and a half long and three feet wide, in which are six holes *c, c*, &c., to receive friction rollers, on which run the boards to receive the dough. Fig. 7 is an enlarged section of the side *a* of the table, *b* is the bed, *c* one of the friction rollers, and *d* the board. The sides *a, a* of the table support a very heavy cast-iron roller *e*, eighteen inches in diameter, which, when resting on the table, is about two inches clear of the board *d*. This roller is made to run alternately, and with great rapidity, from one end of the table to the other, by means of a pair of beams ten or eleven feet long, attached to centres below the floor under the middle of the table, and made to alternate by a crank from the steam-engine; the upper end of one of these beams is seen at *f*, fig. 4, showing the groove in its extremity, to allow the axis of the roller to play in it as the beam alternates. It will now be evident that when a mass of dough or paste is taken from the mixer and placed upon the table, it must quickly be compressed by the roller into a cake equal in thickness to the distance of the roller from the board, which, in this case, is two inches. During this process a considerable quantity of dry flour is sprinkled on the dough and on the board, a large portion of which would be swept off by the roller and lost but for the troughs *g, g* at the ends of the board, which catch and retain it. Notwithstanding this sprinkling with dry flour, a small quantity of dough would occasionally adhere to the roller, were it not kept constantly and perfectly clean by means of two thin knives, extending on opposite sides along its whole length, and attached to two pair of curved arms, one pair of which, *h h*, is seen fixed to the beam *f*; when this operation is finished, the board with the dough is withdrawn, and another board introduced, on which the process is repeated. The first board and dough being withdrawn, is conveyed, on a series of friction rollers, to a second table, precisely similar to that just described, except that the roller approaches to the board within such a distance as is required for the thickness of the biscuit. The dough, which was reduced to a cake two inches thick at the first table, is cut into pieces and laid in portions on the second table, where it is quickly brought down to the proper thickness for biscuits; the board containing this comparatively thin sheet of dough is pushed forward, still running on friction rollers, towards a machine next to be described, while the workmen at the second table repeat their operations on the fresh portions of the dough which they have received from the first.

The machine towards which the board and sheet of dough now roll is shown in fig. 8; it consists of a strong cast-iron frame *a a a*, with cross beams *b*, supporting three or more pair of rollers *c c*, on to which the board is pushed. Immediately above is a thick plate of cast iron *d d*, three feet square, which is made to ascend and descend alternately by an eccentric, which acts on the rod *e*, the lever *f*, and guide rod *g*. The iron plate *d* is shown in the figure at its lowest position; it is, of course, at its highest when the dough and board

Mechanical Processes.
The roller table.

Cutting-out machine.

Manufac-
tures.

Pl. lxxxv.
Fig. 9, 10.

are brought under it. When this is done, it descends and cuts the dough into hexagonal pieces or biscuits, by means of thin knives, one inch wide, affixed to its under surface, and arranged so as to form hexagonal spaces. A small part of the under side of the plate *dd* is shown on a larger scale in fig. 9, where, in addition to a portion of the hexagonal knives or cutters, will be seen a number of small dots or circles, which indicate the pins or prickers, to give the punctures to the biscuits before they are baked. These pins are as long as the depth of the hexagonal cutters, that is to say one inch; they are about one-third of an inch in diameter, and pointed at their extremities. The effect of all these cutters and pins would, however, cause the plate *d* to cling to and lift with it the sheet of dough. In order to prevent this, a very ingenious contrivance is introduced, a part of which will be observed in fig. 9. In each hexagon will be seen three arms branching from the centre; these are formed of iron, and each set is connected with a small vertical iron stem, which passes through the plate *d*, moving easily, and is surmounted by an iron ball two inches in diameter, acting as a weight to press the stem and the arms downwards. One of these balls, with its stem and arms, and a portion of the plate *dd*, is shown in fig. 10, where *a, a, a* are the three arms, *b* the stem, *c* the ball, *ff*, fig. 11, a portion of the dough, and *gg* a part of the board beneath. It will easily be understood that when the plate *dd* rises, the stem *b* will drop through its hole, pressed by the ball *c*, and, acting on the dough by the arms *a, a, a*, will disengage it from the hold of the prickers and cutters. When the plate *dd* descends to cut the dough, of course the arms *a, a, a* rise up to the plate, and the stem rises upwards in its hole, carrying with it a ball. There are as many of these balls and stems as there are biscuits, that is to say, about sixty in each square of three feet. These balls would therefore be seen on the upper side of the plate *d*, in fig. 8, but they are omitted for the sake of avoiding confusion. The hexagonal cutters do not so completely separate the sheets of dough as to prevent their being put whole into the oven, into which it is introduced by being laid on a plate of iron, which fits on the handle of the peel by a bayonet point. The sheet of dough, when baked, is broken into biscuits, which take the form marked out by the cutters.

The arrangement of the several machines would, in some measure, depend on the form of the building and other circumstances. They should be as near together as is convenient, in order that the boards may pass from one to the other on rollers; the mixing machine should be near the supply of water and flour, and the cutting machine should of course be near the oven. A series of rollers should be fixed against the wall, for the purpose of returning the boards to the first table after they have been emptied. At Portsmouth, this series of rollers was kept constantly revolving by the steam-engine, so that when the empty boards were placed upon any part of the line, they travelled up the mixer without further attention.—*Trans. Soc. Arts*, vol. 1.

Malting.

Malting.
History of
the malt
uties.

(1116.) When we consider the immense extent to which malting is carried in this Country, and the great revenue which the Government derives from this source, it will be admitted that, however simple the process may appear in itself, the true theory of it is of very great

importance; and yet, by the various methods followed in different Counties, it would appear that very little is known on the subject. It may be said, in few words, that malting consists in steeping barley in water for a greater or less time; then placing it in heaps till it begins to germinate; and, finally, in stopping the germination, and drying it in kilns for use. Simple, however, as this may appear, the subject was considered of so much importance a few years back as to lead to a Parliamentary inquiry into the methods pursued by different maltsters, who were divided, we may say, into two parties, one of which advocated the practice of sprinkling the malt on the floor, while the other party opposed the practice as exceedingly detrimental to the article produced, and as leading to frauds on the revenue. This inquiry led the Commissioners of the Excise to request Mr. Carr—who had formerly been a Supervisor of Excise, a good deal connected with that branch of the revenue, and who had studied the subject with great assiduity—to draw up his views on the subject; and we think we cannot illustrate the theory of this important process better than by laying before the reader the very clear and scientific theory of malting which he has promulgated, and which is published amongst many other papers in the Parliamentary Report referred to above.

(1117.) *Theory of malting.*—The interior of a barley grain, Mr. Carr states, consists of two distinct parts, a minute germ, destined to elongate into the future plant, and a portion of farinaceous and mucilaginous matter, stored up expressly for its future conversion into saccharine, as the pabulum of the germ in the earliest state of its vegetative existence. Theory of
malting.

The germ itself consists of two very different parts, the plumula (acrospire, in malting) and the radicle or root; both are united at the same end of the grain; but, in germinating, the radicle very soon pierces the husk, and, separating into several fibres, elongates downwards, while the acrospire, but much more slowly, advances through the body of the grain, and, piercing the opposite end, soon shoots up into a green blade, leaving the husk of the corn empty, and perfectly exhausted of its former contents. The radicle is much more rapid in its formation and growth than the acrospire, because, as it is destined to prepare and transmit to the stem nearly all its pabula, it is necessary that it should be sufficiently matured to perform this office by the time the acrospire has consumed the store which provident nature had laid up for it in the grain. There is no difficulty in comprehending the first dawns of vegetative life in the germination of barley; the grain, placed under favourable circumstances of moisture and warmth, imbibes both, and swells much; the radicle, lying the nearest to the exterior, is the most susceptible of these; it swells most, and first, under its new combination of moisture, acquires an attraction for the oxygen of the atmosphere. The oxygen, as it becomes fixed, produces two powerful effects; it gives up that portion of latent heat which held it in a gaseous state, and, by its fixation, enters into a new combination with the farina of the grain, converting it into an oxide, or, in other words, into a saccharine. The stem part of the germ, previously swelled by the moisture, and now invigorated by the heat produced from the fixation of the oxygen, acquires an attraction for the newly-formed saccharine, assimilates it to itself, and in the chemical action of union which ensues vegetative life is developed. Such simply is the natural process of germination in every

Mechanical
Processes.

Manufac-
tures.

species of seed, though here restricted to barley; and it is important to remark, that the heat arising from the fixation of the oxygen is the same which first becomes sensible in the couch, and afterwards continues to show itself in different degrees amongst the corn on the working floors; and in the nice adjustment and due regulation of this heat consist the most important part of the manipulations of malting.

The formation of the saccharine in the grain is slow and progressive, as the acrospire requires it; and hence it may easily be conceived that, between the first formation and final consumption, there must be a period of time when the largest proportion abounds in the grain; and this is the proper time for throwing the corn upon the kiln. Mr. Reynoldson, in his evidence, states that the saccharine previously exists in the barley, and that the process of malting only develops a substance which was already present in the grain; but this, like several other of his philosophical assertions, is so contrary to the natural fact as obviously to refute itself. The chemical and natural characters of malt differ so essentially from those of barley as clearly to prove that there has been not a mere development of a thing present, but an entire change of the original substance into another.

Practice of
malting.

(1118.) *Practice of malting.*—Malting then is nothing more than the promotion of a healthy germination of the barley up to that period when the largest proportion of saccharine has been formed; nor can any thing be more obvious than that, in a variety of modes to accomplish this, one must be superior to all the rest, and that not locally, but every where, because nature is every where the same. In every natural process, the varying of the means will necessarily produce a difference in the end; and, in the two modes of malting, by watering on the floors, or omitting to do so, there is so material a difference, not merely in the use or disuse of the water, but in the time, management, and other circumstances, that the one cannot but be superior to the other in the quality of its respective commodity. A single instance cannot be produced of any natural process whatsoever wherein nature permits the employment of two different means to produce precisely the same end. The application of this to the question of malting will be sufficiently obvious by separately considering the different branches of the case.

The radi-
cle.

The radicle.—This is by much the most important organ in malting; without a root the grain will never germinate, and with too much, the substance of the corn will be exhausted, and the malt on that account will be light and unproductive. This has hitherto either not been sufficiently known or attended to; in this, as in every other natural process, nature herself affords the best explanation. On the richest and best lands the roots of barley are short and the plant large and strong; but on loose and poor soils the roots are long, and the stem small and weak. In the one case the root, having readily found what it was in search of, stops; but in the other, nature is compelled to expend much of the pabulum on the more ignoble part of her production. On the floor of a malt-house the grain is worse situated than on the loosest and poorest land, for it contains no soil at all; and, if permitted, the root there would run out to some inches in length, and almost wholly exhaust the substance of the corn. To prevent this is one of the principal objects in the manufacture of malt, and hence too a just criterion is afforded for estimating the merit of different methods of working; for that method

which will accomplish the full malting of the barley with the least possible root is so far unquestionably the best, because such malt will have expended the least portion of itself on an object entirely unproductive. Now there is, perhaps, no one circumstance wherein the Hertfordshire method of malting differs so distinctly from the watering system as in its short and comparatively small radicle. This may be very clearly collected from many parts of the evidence; for the watering party even seem to have made a merit of it, by endeavouring to show that their own steepings, from the larger quantity of root which they contained, approached and even ran into floor charges far beyond the Hertfordshire steepings; and they thence endeavoured to infer that a larger opening was left in the latter for fraud, by the introduction and mixing of corn privately steeped. It is indeed certainly true that the Hertfordshire mode of working gives the floor gauges low, and the other high; but with this the question of fraud has very little to do, for mixing is seldom, if ever, practised in the whole floors; but the short and small radicle of the one, and long bushy root of the other, are decisive characteristics which are admitted by themselves, and which would, in the author's opinion, stamp a decided superiority on the Hertfordshire malt.

Mechanical
Processes.

That the radicle is actually formed from the body of the barley is too obvious to require any proof, and indeed it is universally admitted to be so; and, as it is afterwards burnt off on the kiln, and becomes mere waste, every particle of matter which it unnecessarily takes from the substance of the corn is just so much loss; and, though this has not been at all adverted to in the inquiry before the Committee, it does, in fact, constitute one of the most important portions of the subject; for it actually is the expenditure of the substance of the barley on the root, by working it too much out, which is the chief cause why malt manufactured under the forcing system of watering the floors is lighter and less productive than the malt made by the Hertfordshire mode without watering.

The acrospire.—In the malting trade a great diversity of opinion prevails as to how far the vegetation of the acrospire should be carried. This arises from a notion very general among maltsters, that just so far as the acrospire penetrates the grain it becomes malted, and that the impenetrated part remains unchanged barley. Mr. Carr says, "I trust, however, that I shall soon show there is nothing either of truth or nature in this notion. The evidence of Messrs. King and Clough sufficiently establishes that the best malt is made when the acrospire proceeds only two-thirds through the grain, and it is my present purpose to prove that their opinion and practice are supported by the natural reason of the case. I have already stated that it is the radicle which first acquires an attraction for the oxygen of the atmosphere, communicating it progressively to the interior substance of the barley, and forming, by its fixation and union with the farina, the first saccharine; and that afterwards the plumula, or infant stem, requires an attraction for the newly-formed saccharine, and by its chemical action is pushed into vegetable life.

The acro-
spire.

"In this statement a solution is given of the question of the acrospire; and the truth really is that the radicle is the only natural organ which malts the barley, or, in other words, oxidates the interior substance, and forms the whole of the saccharine, while the acrospire is simply employed in feeding upon it, and from thence

Manufac-
tures.

acquiring its growth and bulk. This obvious, and I trust just and natural, distinction in the office which nature assigns to each of those different members of the plant, sufficiently explains why the barley may be, and actually is, perfectly malted by the Hertfordshire method, though the acrospire has proceeded only two-thirds through the grain; because, in the more slow and natural growth of the acrospire, the root has had time to malt the interior substance beyond it, and even to the extreme end of the corn, whereas, in the more unnatural forcing of the watering mode, the acrospire is driven forward as rapidly, though without having any immediate connection with the oxidation; and thus an accidental occurrence has been erroneously mounted up into a cause. It is material to remark that, in brewing, the acrospire is insoluble and always appears so among the spent grains; hence the larger it grows, the more it contributes to waste. The preceding account of the radicle and acrospire so far simplifies the question of malting as to concentrate it to this limited rule; viz. that mode of working will necessarily be the best which can accomplish the full malting of the barley, with the smallest radicle and acrospire; for both, as I have already shown, are supported from the interior substance, and just in proportion as they are advanced in bulk, that portion of the malt which yields the fermentative extract will be diminished. In page 40 of the printed evidence Mr. Delafield states that he has found malt made by sprinkling to yield from fifteen to twenty pounds weight in four bushels less than an equal quantity of malt which had been watered; and in page 43 Mr. Martineau states that sprinkled malt affords only sixty-four pounds of extract, when a like quantity of unwatered malt gave as high as eighty-four pounds. Other passages of the evidence also prove that watered malt is lighter, and, on that account, less productive than the Hertfordshire malt; but no explanation of the immediate cause of so material a difference is any where attempted; here, however, it is the opinion of the author that the true cause lies in the comparative smallness both of the root and acrospire in the Hertfordshire malt, whereby less of the substance of the grain is consumed, and that it is the long and bunchy root and large acrospire of watered malt that renders it so light and unproductive."

Tempera-
ture of the
floors.

(1119.) *The proper temperature of the floors in malt-
ing.*—There is no one circumstance in the manufacturing of good malt that merits so constant and careful an attention to the working floors as the temperature. There is a certain maximum of heat that is the best adapted to malting, and with which the vegetation will proceed in the safest and most natural order; either above or below this temperature is a disadvantage, but an excess and fluctuation of heat are highly injurious in a malt-house. In whatever way the floors are worked, the temperature will continue to rise in proportion to the time they lie undisturbed, and the only method of checking the rise is by turning them. Moisture is the remote cause of all heat in vegetable substances heaped together, and containing a farinaceous or starchy matter. This matter passes into a state of fermentation, attracts oxygen from the atmosphere, which, in its fixation, parts with the latent heat it was before combined with, and, this accumulating in the heap, will frequently rise to inflammation. The heat of a dunghill, moist hay-rick, wet barley, and all other similar heaps of wet vegetable matter, originate in one and the same natural cause. In floors of malt the heat is always in proportion to the

quantum of moisture and repose of the floor. The chief object in a well-regulated malt-house is not only to preserve the floors in one equable state of temperature from the cistern to the kiln, but more especially to preserve every part of the same floor in an equal warmth. A departure from this produces an unequal vegetation. In the Hertfordshire method of working, as there never is any increase of moisture after the corn leaves the cistern, an equal and steady temperature in both of the preceding cases can be preserved with much certainty; but, under the practice of watering the floors, it is not practicable to maintain the same equal degree of temperature, either in the progress of the floors to the kiln, or in the different parts of the same floor; and the consequence is that a forced, a fluctuating, and an unequal vegetation is induced in the same steeping, and the malt thereby becomes greatly injured. It is heat in the first instance that dissipates the water which the grain had imbibed in the cistern, and renders subsequent watering necessary. The floors cannot be heated without an expenditure of moisture, for the warmth sweats the water out of the corn, and, when the floor is turned, the moisture on the husk flies off by evaporation; hence though the water is at first the cause of the heat, the heat again renders more water indispensable. The floors in Hertfordshire are never watered, simply because they are never heated; and it is the cool state in which they are kept in the early stage of malting that preserves the original moisture, and induces that slow and natural vegetation so necessary to prevent the substance of the grain from being run out.

Mr. Reynoldson, in his evidence, states that the water imbibed in the cistern is employed in forming the root, and that the root afterwards is employed in supplying the grain; and hence he infers that fresh water is necessary on the floors. This description is tolerably just when applied to the watering practice, but by no means so in that of the Hertfordshire method. In the former the cistern water, as has already been stated, is nearly all expended in the first five or six days by the employment of heat to drive out a rapid vegetation of the root; but in the latter, seven or eight days are necessary to vegetate a less root. It is in this that the two practices differ most from each other. Mr. Reynoldson also states that the water received into the grain becomes decomposed, and after such decomposition exudes from the grain in a state unfit for vegetation; and hence he again infers the necessity of fresh water by sprinkling. This must be said, however, to be an unphilosophical assertion. In the chemical analysis of water only two products are obtained, viz. hydrogen and oxygen; and these, when separated, have never yet appeared in any other form than that of gases. The decomposed water of Mr. Reynoldson is nothing more than the pure water imbibed in the cistern, and injudiciously sweated out on the surface of the grain.

In order to preserve the floors at a uniform temperature, and to admit of the free dissipation of the moisture arising from the process, a malt-house is supplied with what is well known under the denomination of a cowl, which is a somewhat conical cap open on one side, and having a vane or arm on the open side, so fixed that, as the wind shifts, the cowl shall turn on its spindle, and always present the boarded or close side to the weather, which prevents a drifting rain from beating in: but in still weather the rain will find admittance, which if the floor is loaded with malt retards

Mechanical
Processes.

Substitute
for the cowl.

Manufac-
tures.

the drying, and produces in some measure the evils of watering on the floor spoken of above.

Another inconvenience of the common cowl is that it prevents a proper regulation of the fire, except by varying the supply of fuel, so that in making high-dried malt it is by no means uncommon for the grain on the kiln to take fire, to the imminent danger of the premises. This consideration has led to the invention of a cap for a malt-kiln by Mr. Perkin, for which he received a reward from the Society of Arts. See vol. xlv. of their *Transactions*.

Pl. lxxxvi.
Fig. 1, 2, 3.

This is represented in plate lxxxvi., fig. 1, 2, where *a a* is the turn-cap, and *b b* the neck, in section; *c c* is a square iron bar or spindle sliding through a square hole in the middle of the iron plate or bar *d*, and through another in the middle of the beam *e*. The cap *a a* turns upon the upper cylindrical portion of the bar, and the bar itself is supported and hangs entirely on the chain *f* attached to the pulley *g*, which is mounted on a carriage on the beam *e*. On the same axis is a larger pulley *h*, with a chain attached to it at *i*, from which hangs a weight *j*, sufficient to balance the weight of the sliding bar *c c* and turn-cap *a a*. By raising the weight *j* the cap is lowered and finally shut, and on lowering the cap is raised quite up, or held at any intermediate height: *d e*, fig. 2, is a section of the neck between the bars, and fig. 3 a top view of the bar *d*, showing the hole through which the spindle passes; *k*, fig. 1, being a similar iron bar across the cap *a a*. The chain *f* should be attached quite close to the bar *c c* to lessen its tendency to lean on one side.

Effect on
the flavour.

(1120.) *Flavour of malt*.—A great deal is said by the party for watering on the subject of their being enabled to make their malt of a superior flavour by sprinkling; but the question of flavour, when applied to pale or common malt, resolves itself into this simple fact, that malt which is worked in the most pure, clean, and natural manner will be the most free from all adventitious and improper flavour. While pale malt is worked on the floors, all that can be done is not to give, but to guard it from any peculiar flavour. On the kiln the case is widely different; there, just in proportion as the fire is urged slowly or rapidly, less or more of flavour and colour will be given to the malt; it is in this way only that all malt expressly intended for the brewing of porter has its peculiar flavour and colour given to it; but the flavour of ale, generally speaking, is derived from a different source. This latter arises from the union of a peculiar oil of a greenish colour, naturally abounding in hops, with a portion of the unfermented wort, and the mucilage and alcohol of the fermented parts; these, judiciously blended together in a due proportion, give to ale its agreeable taste; but the palate being an arbitrary organ, and differing widely in different places, no established rule can be laid down for adjusting the flavouring of ale. In some places the sweet taste of malt is required to be pretty full in the mouth, by leaving a larger proportion of the unfermented wort; while in others it is required to be almost entirely dissipated by a more complete fermentation; and between these a variety of flavours may easily be imagined. What has been said will be sufficient to explain the case so far as regards that flavour which it is desirable to obtain; but there is another point of view in which it is to be considered, and that is, those bad flavours which malt acquires in its progress through a manufacturing state, and which greatly depreciate its value. The principal

of these, and indeed the only one with which the present inquiry is immediately connected, is that of mouldy malt, arising from the vegetation ceasing after having made some progress. Most of the grains which are bruised by being trodden under the feet of workmen or others while in a state of malting pass into a mouldy or putrid state; but the principal source of mouldy malt is in wet grain being buried under other corn, and too long excluded from the influence of the atmosphere. A simple experiment will sufficiently illustrate this: if a sample of half-malted barley be placed under a bell glass, air-tight at the bottom, the corn will vegetate freely until the enclosed oxygen is all consumed, when the vegetation will cease, and the grain will pass into a state of decay similar to mouldy malt, and the more moist the grain was when enclosed under the glass, the sooner it will become mouldy.

Mechanical
Processes.

In watering on the floors it is invariably the practice to turn over the grain immediately after it has been sprinkled; hence the wet corn is placed at the bottom; and it will necessarily happen that some of this will again be thrown undermost in the subsequent turnings, and this cannot fail to destroy the vegetation, and to render such grain mouldy; and not only the grains individually dead, but all others with which they happen to come in contact, will acquire a disgusting taint, which will afterwards materially affect the flavour of the liquor drawn from the malt.

(1121.) *Weight of malt*.—Several erroneous opinions are delivered in the evidence given before the Committee respecting the goodness of malt being determined by its weight. Abstractedly considered, weight indeed does not afford any certain data for estimating the worth of malt, because bad malt may be either heavier or lighter than that which is good. If the vegetation of the grain has been imperfect, or not carried sufficiently far, the product will be part malt and part barley, and of course heavier than good malt. But if, on the other hand, the vegetation has been carried too far, too much of the substance, and of course weight, of the grain will have been driven out, and the malt will be light in proportion as the injuring cause has been allowed to operate. In this way malt may be rendered light and unproductive to any extent at the discretion of the maltster. But, notwithstanding all this, in every instance where the grain has been perfectly malted, weight is the only certain standard now known for determining the value of malt; and this is now so well understood in the markets that it is not unusual for the buyer of malt to be provided with a pair of scales and a small measure, and to govern his opinion of the price by the weight which his measure of the sample yields. In all malt, therefore, which has been perfectly malted, there can be no question of the heaviest being the best; and in this respect the Hertfordshire malt preserves a distinguished superiority over all watered malt.

Weight of
malt.

(1122.) *Varieties of malt*.—Strictly speaking there are only three, viz. brown, amber, and pale malt. The first two are peculiar to porter, and have special reference to its flavour and colour; the third is the general basis as well of all porter as of every species of malt liquor, and it is the only one which merits any consideration in the general question of malting. Brown malt receives all its peculiar qualities in the kiln, by an operation called blowing. It is spread there very thin, and a very quick and active heat is passed through it from flaming faggots. The sudden application of the

Varieties.

Manufac-
tures.

heat converts the moisture in the grain into vapour, which blows up the husk, and the heat catching it in its distended state hardens and prevents it from collapsing; hence the grains of such malt are large and hollow, and increase the measure from one to two bushels in a quarter. The saccharine of this malt is nearly all destroyed by the operation of the fire, and its sole object in porter is to communicate flavour and colour; but as these qualities are probably to be obtained from other materials than malt, some porter brewers are not using it at all, and the making of it is very rapidly declining. Amber malt is a species between brown and pale, and is also made on the kiln by giving it less fire than the former and more than the latter. It is still generally used in porter along with pale malt, but the quantity made is inconsiderable.

Revenue.

(1123.) *Revenue derived from malt.*—The first malt tax was established in England during the reign of Charles I., but assumed a more particular character in the reign of William III., when, in 1697, a duty of 6d. per bushel was imposed. This was at first given for two years and a quarter, but was afterwards granted from year to year. The first permanent duty on malt was granted in 1760, at the rate of 3d. per bushel: a further addition to that was made in 1779 of 15 per cent.; and in the next year, 1780, another permanent addition was made of 6½d. ²/₁₀ per bushel. These several duties were consolidated in 1797 into one permanent tax of 9½d. per bushel, in addition to the old tax of 6d. per bushel; a further permanent addition was made in 1802 of 1s. 0½d. per bushel, and in the following year a war addition of 2s. per bushel; so that in the latter years of the War, and for some time after, the total malt duty amounted to 4s. 4d. per bushel. Gradual reductions have since been made, as will be seen by the following Table, which shows the amount of the malt duties for twelve years; viz. from 1820 to 1831, with further particulars therein stated.

TABLE, showing the Quantity of Malt made in England and the Revenue on the same, from 1820 to 1831.

Years.	Produce of duty on malt in each year, from 1820 to 1831, both inclusive.	Number of bushels charged with duty in each year, from 1820 to 1831, both inclusive.	Quantity imported into Great Britain from Ireland in each year, from 1824 to 1831, inclusive.	Quantity brought into the Port of London in each year, from 1820 to 1830, inclusive.
1820	5,088,195	27,889,210	....	195,878
1821	5,360,705	32,088,466	....	214,673
1822	3,918,001	28,282,292	....	221,108
1823	3,251,334	28,168,658	....	232,309
1824	3,999,419	32,573,990	1,173	233,638
1825	4,384,163	36,295,843	10,826	256,813
1826	3,955,935	32,468,778	1,202	275,787
1827	3,601,042	29,613,502	571	241,756
1828	4,623,113	36,794,520	853	229,934
1829	3,814,305	29,153,675	2,011	226,723
1830	3,436,271	35,160,809	2,820	218,261
1831	4,359,333	40,334,987	10,888	

(1124.) *Revenue on hops.*—Although the revenue on hops is not, in reference to our Work, necessarily

connected with that of malt, yet they are so collaterally combined that it will not be thought inconsistent to give the following historical sketch of the revenue arising from hops, derived from an authentic source, viz. The Report of the Commissioners of Excise Inquiry.

The first duty on hops was imposed by the 9th Anne, c. 12, at 1d. per pound. It was fixed at its present rate of 2d. per pound by the 45th Geo. III. c. 94.

The duty does not extend to Ireland, but hops imported from thence pay the English duty.

No drawback is allowed on hops exported to Ireland; but a drawback of the whole duty is allowed on hops exported to the Isle of Man and to foreign parts.

A return of the rates and amount of duty since 1770 is given at page 3 of the Report, showing the extraordinary fluctuations of the duty, varying from £14,913, the lowest amount in any one year, viz., in 1783, to £476,895, the highest amount, which was in 1826.

A return is also given of the number of acres under cultivation for hops in each year since 1807, which shows a gradual increase since 1832, the number of acres cultivated in the three following years having been,

In 1832 47,101 acres.
1833 49,187 „
1834 51,273 „

The number of persons surveyed in 1834 is stated to have been 7242, being the greatest number surveyed under any one of the growing-duty trades, except that of malt.

A full statement is given in the Report of the regulations for charging and collecting the duty on hops, which objects are carried on in a different manner from that of the other duties of Excise, being invariably completed in a period of one or two months, temporary assistant officers being employed for the purpose, which has been found more economical than employing a part of the permanent establishment of the Excise.

The total number of such officers has been in each of the last three years 270, and the total expense as follows, viz.

In 1832 £3316
1833 3432
1834 3675

forming a very small per-centage on the revenue derived from a good crop.

It appears, from letters addressed to the Commissioners by Members of Parliament representing the hop districts, that the growers are generally satisfied with the present arrangement for the collection of the duty, and are not desirous of any change, either in the rate of duty, or in the regulations under which it is charged.

The Commissioners call attention to the evidence of Mr. Ellis, of Barming, as entitled to particular weight, from his being the most extensive, as well as one of the most experienced cultivators of hops in the Kingdom, the number of acres cultivated by him being at present 500, the greatest number cultivated by any other person being 164 acres.

Sir Francis Doyle and Mr. Dehany consider the duty to be well and cheaply collected: but they suggest that the period allowed for claiming the drawback on hops exported, which is now indefinite, should be restricted to three years from the growth. The Commissioners of Inquiry recommend the adoption of this suggestion.

Mechanical
Processes.

Manufac-
tures.

Mr. Dehany also suggests the extension of the duty to Ireland, by which one of the few remaining distinctions which prevent the trade between the two Countries from being in all respects a coasting trade would be removed; and he considers there will be the less objection to it, as there are very few, if any, hop-growers in Ireland.

The Commissioners express their concurrence in Mr. Dehany's suggestion.

The question of the extent of credit which is allowed by law to the grower of hops, before his duty is collected, is fully entered into in the Report.

By the original Act of Anne a credit of six months was allowed, but under the 1st and 2d Wm. IV. c. 53, a full year must now elapse before the duties are entirely discharged: an extent of credit very much exceeding that which is allowed in any other case. It will be sufficient here to state, that the Commissioners of Inquiry refer to their Reports on paper and on malt, in which they have fully explained the opinion they entertain, "that Excise duties ought to be collected upon the articles charged, as soon as those articles shall be ready to be disposed of by the maker;" an opinion which they conceive to apply with greater force to the case of hops, in which a much more protracted period of payment is given, although the sale of hops generally takes place as soon as they are ready for consumption.

The Commissioners, however, express their sense of the difficulty of withdrawing an indulgence which is in part coeval with the imposition of the duty itself; but, being persuaded of the mischief which arises from the extension of credit in Excise duties, they recommend that the attention of the department of Excise should be called to the possibility of effecting an arrangement on terms satisfactory to the planters, under which this duty might, with respect to the time of payment, be assimilated to the other duties of Excise.

The Commissioners conclude their observations by a few comments on the effects which the high customs' duty of £8 11s. per hundred-weight on hops imported from foreign Countries has, in confining the supply in a great degree to the home grower, and thereby increasing the cost to the customer in England; a species of monopoly which would prevent the consumer deriving the benefit of a reduction of duty, by a corresponding reduction of price in the market; and, under these circumstances, they express their opinion, that there seems to be no reason why the revenue should not benefit by the present amount of duty, more especially as hops are comprised in that class of articles to which they have already referred in their Seventh Report, as being more fitting subjects for taxation than those which may be reckoned among useful manufactures.

Porter Brewing.

Porter
brewing.

(1125.) In our alphabetical division we have an Article descriptive of the process of brewing on a small scale for domestic purposes; we shall confine ourselves here, therefore, to a description only of the processes and machinery employed in the larger establishments, particularly in our metropolitan porter breweries.

Porter originally differed only from other kinds of beer of the same degree of strength by being brewed from brown or high-dried malt, which gave to it the peculiar colour and flavour which distinguish it from other beer, as described in Art. 1122; but at present it is brewed

from a mixture of pale and brown malt, the colour being less than formerly, or with all pale malt, and the colour given to it by certain colouring matter, such as burnt sugar, or burnt sugar of concentrated wort, &c. All London porter is professed to be what is called entire butt, that is, of one kind only; but it is more commonly compounded of two kinds, or rather the same liquor in two different stages, the due admixture of which is palatable, although neither is good alone: the one being new or mild, and the other staler or old; the former is that which has the slight bitter flavour, from having been lately brewed, the other gives the pleasant astringent character which distinguishes good porter. This mixture, however, is not made by the brewer when he supplies publicans with it for sale. In these cases the two different qualities are sent in different barrels, and the publican mixes them to the taste of his different customers, which was done formerly in the cellar; but this department of trade, like all others, has benefited by mechanical contrivance; and the matter is now so managed that pipes are communicated from different barrels in the cellar to a beer pump in the bar, and the beer is thus drawn and mixed with the greatest facility. The usual beer machine has four pumps, but only three spouts, because two of these pumps are connected with one spout. One of these two draw from the mild and the other from the stale barrel, and the tapster, by a dexterous management of the handles, works the two pumps so as to draw in any proportion from each; and to an indifferent observer, as all the liquor is delivered from one spout, no mixing would be suspected.

The London brewers, in consequence of the large scale of their business, have been led to study with the most minute attention every thing which can tend to improve their beer, or to economize the materials of which it is composed, as also to diminish the labour of removing such large quantities of liquor from one part of their extensive premises to another, and to substitute as far as possible mechanical power for that of horses and men.

The first porter brewer in London who erected a steam-engine for this purpose was the late Mr. Goodwynne, and it was the first engine erected in London by the late Mr. Watt. Another was soon after put up by the celebrated brewer Mr. Whitbread, at his establishment in Chiswell-street, where many other improvements were introduced. Indeed it is commonly asserted that the steam-engine was first erected on these premises, which is, however, a mistake. The writer of this article has been assured by Mr. Goodwynne that when Mr. Watt proposed to Mr. Whitbread to erect a steam-engine on his premises he decidedly refused, and that Watt subsequently applied to him, that he agreed to make the trial, and that this was the first steam-engine which Watt erected in London. Whitbread's was, however, for a long time the most scientifically arranged brewing establishment; but at present, we believe, this claim is due to the Golden-lane brewery.

The water employed by the porter brewers in London for the brewing part is mostly drawn from deep wells, although a very popular notion prevails that it is the Thames water which gives to London porter its peculiar quality. This is, however, erroneous. There is an immense quantity of water below the London clay which is in communication with springs considerably elevated; so that by sinking a well 150 or 200 feet deep, so as to penetrate and pass through the clay, an almost un-

Mechanical
Processes.

Adoption of
the steam-
engine in
breweries.

Source of
the water
for the
London
breweries.

Manufac-
tures.

bounded supply of the very finest water is obtained, and is generally employed by the London brewers: the other water supplied to these works by the different water companies being only for the purpose of cleansing &c. Referring again to the wells, the moment the clay is pierced the water rushes up so violently, in consequence of the height of the reservoirs in the chalk with which it is in communication, as to fill the whole of the well even to overflowing in a few minutes. With this pressure the sand between the clay and the chalk is forced into the well with the water, so as nearly to fill it up, and thus obstructs the free passage of the latter. This is remedied by driving down a copper pipe before the clay is quite pierced, and then boring out the part filled into the pipe. When the borer is removed the water again rushes in, bringing sand with it, but of course in less quantities, which, as the upper end of the pipe is many feet above the bottom of the well, affords room for lodging the sand without choking the well; and while the water is not drawn too rapidly, the supply is plentiful and uniform.

The source of water being thus secured, it has to be raised into the reservoirs, of sufficient height to supply the whole brewery by the steam-engine, which also works the machinery. From the reservoirs pipes are laid to convey the water to any vessels in the work where it may be required. The principal of these are the coppers, of which there are two, three, or more, according to circumstances. The water being heated in the coppers is conducted by a pipe to the mash-tuns. During the process of mashing, the malt is kept constantly stirring by machines in each tun, turned by means of bevel gear connected with the steam-engine.

Crushing
rollers for
preparing
the malt.

(1126.) The malt previous to mashing is ground or crushed, to render the husks pervious to the water, either by millstones or crushing rollers, turned also by machinery connected with the first mover. These rollers are about 18 inches in diameter, and 2 feet 6 inches in length, and are situated at such a distance that only a piece of thick brown paper can be passed between them. Immediately above these is a third roller, which has a number of deep flutes or cavities cut in it from one end to the other, and these, as it revolves, become filled with malt from the hopper above, and which it delivers into the two rollers: these, being in motion, take it between them and crush the grain flat. By means of this feeding roller the supply of malt to the crushing rollers is regulated and preserved uniform, which is essential to prevent the latter from becoming clogged or filled up. When the malt has passed through the rollers it is of course found completely broken, but very little of it is cut into flour, for the husks of the malt, although crushed sufficiently to admit the water, still prevent the flour being separated, which is considered to be a great advantage over the method of grinding; because that produces a quantity of flour which is the richest part of the malt, but when it is ground and separated from the grain it does not produce so much extract in the mash-tun as when it is preserved in the grain, and the husk sufficiently broken. This is because the flour, when immersed in the water and wetted, forms a sort of paste; this at first absorbs a considerable portion of water which will not afterwards quit it, so that very little extract is obtained from that portion of the malt which is separated from the grain in the form of flour. It may be observed that the malt being brought to the premises in waggons is raised to the

upper floor of the building in sacks by the usual lifting apparatus, as described under Flour-mills. Here it is emptied through holes in the floor in the great malt store lofts, whence it is passed, when required, through shoots to the rollers above mentioned.

Returning again to the malt-crushing rollers, the grain in passing through these fall into a large chest, whence it is conveyed to the malt bins situated over the mash-tuns, by the motion of an inclined screw, somewhat resembling the Archimedean screw, by which it is raised to the point required. The screw itself is formed of thin iron plates bent into a spiral, and fixed by nails to a wooden axle which revolves with the mill. When the malt is required for mashing, it is let down from the bins through sluices or shuttles in the bottom of it, and curtains are hung round from the bin to the edge of the tun to prevent loss from the dust or flour of the malt flying into the air.

The water being heated in the copper is conducted by a pipe to the mash-tuns by the means which will be described as we proceed, and is there kept in constant motion by the machinery, also to be described, in connection with the first mover; and after this process has been continued a sufficient time, the extract or wash is drawn off from the mash-tuns into others beneath them, which are called the lower or under backs, where it remains only till the coppers are ready to receive it again to be boiled. It is then forced by pumps, worked either by horse or steam power, into what is called the copper back, which is a shallow cistern placed above the coppers, or into their pans, which are vessels placed over the coppers, their contents receiving heat from the steam raised by the boiling of the copper itself.

(1127.) This will be understood by referring to plate lxxxvi. fig. 4, which is a section of the close copper now commonly used in breweries. A A is the fire-grate, B B C the copper itself, containing from 200 to 500 barrels. Its top is a dome, having a cylinder G rising from it. F F is the pan erected on the top of the copper, enclosing the dome C within. This pan is heated by steam rising from the cylinder G, and thence descending by pipes d d down into the liquor, and bubbling up through it. The heat communicated through the dome also assists in heating the contents of the pan. In the head or cylinder G are two valves, which are kept shut by steelyards and weights; but these being opened, the steam of the copper is allowed to escape through a pipe into the open air. E is an iron door to allow entrance into the copper, and also to admit the hops. It is situated in the top of a cylinder rising from the dome, and is fitted so close by grinding, that it is steam-tight when shut, and forced down upon its seat by a screw. Two flues proceed from the fire-grate at the further end, and conduct the flame and heated air round in opposite directions, as shown at D D, to the chimney, which is placed over the fire doors, and thus the heat is applied to the sides as well as to the bottom of the coppers. This, as the figure shows, is made concave beneath, to allow a greater action to the fire. The chimney is open at the bottom, and therefore the draught it occasions through the flues is only by the lateral action of the current of air in the chimney; but this draught can be cut off when it is required to damp the fire. In some breweries doors are provided to shut up the bottom of the chimneys, and thus increase the draught by compelling all the air which enters the chimney to pass through the fire-grate,

Mechanical
Processes.

Copper
described.
Pl. lxxxvi.

Manufac-
tures.

and thence by the flues into the chimney. This causes the copper to boil much quicker; but the violent heat soon destroys the bottom, by burning or melting the metal. When the hops are boiled in the copper, they are kept in constant motion, to prevent their lying upon the bottom and burning it. This is done by a machine called the *rowser*, contained within the copper: it consists of a vertical spindle *e*, in the centre of the copper, which at its lower extremity has a cross arm *g*, curved, to correspond with the bottom, and from this a number of loops of heavy chain are suspended, to drag round upon the copper when the spindle is turned. By this means the hops are raked over and continually disturbed. The spindle passes through a stuffing-box in the centre of the top *G* of the copper, and is turned round by the wheel *f*, engaged with another upon a shaft receiving motion from the engine.

The copper is provided with a float, to show the height of the liquor within it. This consists of a strong wire passing through a tight stuffing-box in the top of the copper, suspending a stone at the lower end of it. From the upper end of the wire a line is conducted over pulleys, which has a ruler or rod divided into feet and inches suspended from it, with a weight greater than the weight of the stone when it is suspended in the liquor, but less than the weight of the same when it is drawn up out of the liquor. In this situation the stone will always be at the surface of the water, in the same manner as if it floated, and will show the height of the liquor in the copper. There are several pipes and cocks belonging to the copper, which are as follows: a pipe leading from the liquor back to introduce the water into it; this has a cock formed of two passages, one for admitting it to flow into the pan, and the other for conveying it by a short pipe into the copper itself, and the handle being turned in one direction or the other shows which way the liquor will run, and turned in another it will be stopped altogether. There is also a hole in the bottom of the copper back, through which the contents run down into the pan. This is closed when requisite by a plug, and near it is a pipe leading down through the pan into the copper. This is closed by a valve which can be opened with a lever and screw, when it is required to convey the wort from the copper back into the copper itself. There is also a valve which communicates at once from the pan down into the copper. From the bottom of the copper is a large cock with a pipe, which runs horizontally over the mashing-tuns, and in every one a branch of the pipe descends below the bottom of the tun and then turns up, with two or three small branches leading to different parts of the bottom. By this means the hot water is admitted from the copper into the tun and diffused pretty equally through the whole mass of the malt. Moreover, to assist in this essential particular, the tun has a false bottom full of holes, on which the malt lies, and through which the water rises in all parts at the same time.

Different
Patents for
brewing
coppers.

Before quitting this part of our subject, it may be well to say a few words more relative to the copper. We have described it as closed, which it is now in all large breweries. They are found to effect a great saving of fuel, and at the same time to prevent in a great measure the waste of the saccharum and flavour of the hops which passed off with the steam in the old open boiler, as was obvious from the strong scent of those substances diffused from a large brewery to consider-

Mechanical
Processes.

able distances. In the close copper, the steam being passed through the liquor contained in the pan, the above substances are in a great degree condensed and retained in the liquor. At the same time the liquor in the pan is heated, and, being let down into the copper as soon as the other liquor is run out of it, it is quickly boiled, thereby saving much time and fuel. Mr. Goodwynne, whom we have spoken of as having been the first brewer who employed a steam-engine for such works, was also the first to introduce the use of the pan over the copper for the purpose of heating one liquor by the other. This was done as early as 1780, but the steam did not in this case pass through the water. It was about five years later that the steam pipes were introduced by Mr. Bramah, at Hartford's brewery.

Since that time various Patents have been taken out for improvements in brewing coppers. Mr. Richard Hares took out one in 1791 for the construction of a steam head to the copper, but the Patent was set aside by a trial in the Court of King's Bench, on the ground of not being a new invention. In the use of a large brewing copper great attention is requisite, in taking care that the copper is never empty whilst the fire is burning; for, in a few minutes, the bottom of an empty copper would be melted by the intensity of the heat. The fire may always be immediately damped by opening the fire-hole and chimney doors. The cock is opened, and as soon as the brewer can see the bottom of the copper, he lets down the contents of the pan; frequently it is found necessary for the men to go down into the copper and scrape away all the fur which adheres to it from the stony matter contained in the water; for if it was allowed to accumulate for a few days, it would prevent the water from coming into actual contact with the metal, which would, in that case, be quickly melted or burnt through. The copper plates are not less than three inches thick in the centre of the bottom, but diminishing to one inch thick against the flues. They are united by rivets two inches in diameter, and with heads five inches in diameter. When it is required to repair a copper, a new plate is put into its place while red-hot, and hammered down to fit the edges of the plate with which it is to be connected. The plate is then heated again, and holes punched through it in the proper places for the rivets, which are put in red-hot while the plates are cold; they are introduced through the holes from the lower side, and a workman, standing upon the grate, has a hand-jack, which he screws up under the head of the rivet to hold it fast in its place, and immediately three men within the copper batter down the end of the rivet with the utmost expedition. In such thick plates it is almost impossible to get the ends quite close; but the contraction of the rivets in cooling draws the plates together so forcibly as to make them nearly tight, and the leaks cease as soon as the fire is lighted. The very great expense of these repairs, and the loss occasioned by all the works being stopped, render any form of the fire-place which tends to preserve the copper of very great importance. An improvement in the construction of fire-places was made by Mr. Woolfe, who applied it to the coppers at Messrs. Meux's brewery. The same ingenious engineer also erected at the same works an apparatus for heating water by the waste steam which passed off from the coppers. This is described in Nicholson's *Journal*, vol. ii.

Another Patent was taken out by Dr. Sharman, which

Manufac-
tures.

Mashing-
tun.
Pl. lxxxvi.
Fig. 5, 6.

is a cylinder laid with its axis horizontally having flues for the flames passing round it after the manner of a screw, the steam of the copper being condensed in a vessel for the purpose, and the product returned to the copper. Mr. W. Ker had also a Patent taken out in 1788 for a similar manner of condensing the volatile part of the malt and hops.

(1128.) *Mashing-tun*.—The next important machine in the process of brewing we have to describe is the mashing-tun. This is commonly a large wooden vessel, formed of vertical staves bound by iron hoops; but it has lately been made of cast iron in our larger brewing establishments. It has a false bottom, to which allusion has already been made, pierced with a great number of small holes to admit the liquor to pass from the bottom, where it is admitted up through the malt. It has been already stated that the water is brought by pipes from the copper, and delivered at the lower part of the mash-tun under the false bottom, whence it forces its way up through the malt; and when it appears above it the malt (technically the goods) is stirred up to expose every part to the action of the liquor. This was formerly performed by manual labour; the men first using long rakes to level the heap of malt, and afterwards rowing the mass with large oars. But the present extent of the London breweries would render this mode too slow and expensive. Mashing machines are now, therefore, generally adopted. Various contrivances have been had recourse to and adopted at different breweries, but the following for a cast-iron mash-tun, by Mr. Cooper, is perhaps the most effectual.

This machine is represented in fig. 5, 6, plate lxxxvi., the former being a plan and the latter a section of the mash-tun and mashing machine; but, to save room, only one half is represented. The reader will, however, readily imagine another half to each figure.

AA, fig 6, is the level of the stage floor in which the mash-tun is placed; BB is the tun, formed of a number of cast-iron plates screwed together, the disposition of which at the bottom is shown in the plan, fig. 5. The vessel is supported upon eight cast-iron columns DD, which are united at their upper ends by the cast-iron frame E, which confines them in a vertical position, and connects them with a central column, fig. 6. This is cast hollow to form the continuation of a pipe G, which brings the liquor into the tun from the copper as already described. There are branches to this pipe for distributing the water under the false bottom, which arrangement has also been referred to.

Fig. 7, 8.

In the centre of the tun is set up a vertical axis K, which is turned round by wheelwork communicating with its upper end, as in fig. 7. Upon this axis are two bevelled wheels *a b*, giving motion to the mashing engine. These wheels turn two horizontal axes, L, M, extending from the centre to the circumference of the tun. The former has four wheels upon it, over which four endless chains pass, as also over another horizontal axis N, near the bottom of the tun. Upon this endless chain cross pieces of iron, *d*, are fixed, having teeth in them, as shown in the upper and lower piece, fig. 6, and also in profile in fig. 7. These, as the chains revolve by the action of the wheel *b*, raise up the malt from the bottom to the top of the tun. That this may be performed in all parts of the tun, the frame containing the axes L, M, N has a progressive motion round the tun. This is thus effected: on the curb or upper edge of the tun is a range of teeth *o, o*, fig. 5; these are

engaged by an endless screw, which is mounted in a frame P, fig. 8, and which receives its motion by means of wheelwork connected with the axle above described, and the frame is thus made to have a slow progressive motion of rotation round the tun.

R is the under back, which is placed between the iron columns upon brickwork supported on bearing piles. This is also formed of cast-iron plates in the same manner as the mash-tun above described. The use of this vessel is to receive the liquor from the mash-tun after the operation of mashing is completed, and from which it is drawn off again by pumps and conveyed to the copper to be boiled with the hops, after which it is transferred to a broad, shallow vessel to be cooled; it is then fermented, and ultimately cleansed and placed in the proper store vats till called for.

We have confined our description of the mash-tun strictly to one in cast iron; but many different forms have been given to this important brewing vessel: of these, one was erected at Goodwynne's, the figure of which was that of a half cylinder placed horizontally, and on the central line or axis an iron shaft was fitted and turned round by wheelwork from the steam-engine. It had several iron arms fixed perpendicularly upon it at different parts of its length, which, as the shaft revolved, swept the whole contents of the tun; and, having teeth in them, they performed very effectually the mashing process. These arms were not all fixed on the same side of the axis, but were arranged at equal angles round it, so as to dip into the malt in succession; and this had a tendency to accumulate the malt towards one end, but the motion could be reversed which carried it back again.

Another mashing apparatus was constructed by Mr. Silvester for Messrs. Clowes. This consists of a vertical spindle in the centre of the mash-tun; and upon this an iron arm, of a length sufficient to extend across the diameter of the tun, slides up and down through the depth of the grist. The arm is provided with teeth projecting from one side of it like a rake; and these teeth are so contrived that when the arm descends they hang down vertically, and their points penetrate the goods without disturbing them; but when the arm reaches the bottom of the tun, the teeth are turned by the machine so as to be horizontal, and are then drawn up, during which action they raise a portion of the grist from the bottom to the top. The next time the arm descends, it is turned round with its spindle a few degrees, so as to take a fresh portion of the tun; and in this manner its action continues till, in about thirty or forty strokes, it completes its revolution round the tun. This construction admits of the mash-tun being covered close over by large doors, a circumstance of great importance for retaining the heat.

Various other machines for facilitating the process of mashing have been projected and patented, which our limits will not admit of describing; nor is such a description actually necessary, our object having been simply to give a general idea of the principles on which this important national beverage is obtained in our larger establishments.

(1129.) The extent of the brewing trade will be seen by the following statement of the quantity made and the revenue derived from the duty on beer from 1820 to 1830. The duty has been since repealed, and, of course, the quantity brewed largely increased.

Mechanical
Processes.

Manufactures. TABLE, showing the Number of Gallons of Beer brewed for public Sale and the Amount of Duty, from 1820 to 1830, inclusive.

Years.	No. of Barrels strong.	No. of Barrels Table Beer.	No. of Barrels intermediate.	Duty on all.
				£.
1820	5,413,001	1,651,297	....	2,543,713
1821	5,699,277	1,646,141	....	2,609,463
1822	5,838,339	1,716,112	....	3,143,385
1823	6,512,645	1,709,377	7,018	3,221,173
1824	6,774,938	1,784,004	15,660	3,375,936
1825	7,142,446	1,870,934	6,160	3,456,078
1826	6,812,131	1,874,988	7,707	3,316,491
1827	6,507,929	1,773,605	17,759	3,160,817
1828	6,667,933	1,777,862	62,617	3,256,186
1829	6,060,247	1,609,853	55,498	3,055,453
1830	3,645,594	1,244,273	41,834	2,345,122

Distilling.

Distilling, first invention of, by Villeneuve.

(1130.) The Art of distilling, with a view to the production of spirituous liquor, seems to have been the invention of a Frenchman in the XIIIth Century of the name of Villeneuve, who was a distinguished chemist or alchymist of that date, from which time to the commencement of the present century slow but progressive ameliorations were introduced; but since that time the progress of improvement has been very rapid and important. M. Dubrunfaut, in his Treatise on Distillation, gives also the honour of the first great step towards the modern practice to another Frenchman, M. E. Adam, whom he states to have been "an obscure person, unacquainted with Science, and ignorant of the Art he undertook to improve;" but who, notwithstanding, established a new system, "and, with a giant's pace, arrived at that point which the most profound geniuses had never been able to attain, after the continued labours of many centuries." If, he continues, "Raymond, Lully, Portas, Lavoisier, Meusnier, or Fourcroy had made such a discovery, one might have admired their genius without being surprised at their science; but that a man who had not even the first notion of the Art in which he was engaged, and who had not the least experience in the manual operations, should rise all at once, and at his first trial ascend to the acmé of the science, is certainly extraordinary."

Great improvement by Adam.

This great step, according to M. Dubrunfaut, was made in 1801; since which time, however, much has been done to render still more perfect the Art of distillation, although the principle has remained unchanged. The processes or modes of distillation may be classed under two heads. In one, the method is to cause the evaporation, by means of heat, of the mixture of two liquids, to receive the vapour that rises from the one into a vessel in which they are condensed by cold, and to collect the liquor thus condensed. In the other, the method consists in causing the same evaporation of the mixture of the two liquids, to receive the vapours in a vessel where, by the assistance of caloric prudently administered, the whole undergoes a complete analysis, with a separation into two distinct parts, whereof the one which is spirituous is collected on one side after being condensed by cold, and the other part, which is

Different modes of distillation.

aqueous and condensed during the process, on the other. Mechanical Processes. The first mode of distillation was generally followed till about the beginning of the present century, when the great revolution in this Art took place by the discovery of M. Adam; which consisted, however, principally in availing himself of Woulfe's apparatus for the distillation of wines, described in the *Phil. Trans.* for 1767, and the economical method of obtaining heat recommended by Count Rumford. It is necessary, therefore, before we attempt any description of the improved method, to make the reader acquainted with what is commonly known under the denomination of Woulfe's apparatus for distillation; which consists principally in causing the vapours as they arise to pass through successive vessels partly filled with water, and to cause the gas to pass through as many such as are requisite before it is allowed to escape; and even at the last it may be detained by connecting the tube from the last vessel with a gas holder. This had reference principally to distillation in a small way; but Adam applied it in the large way for alcohol from beer or wine, by bringing a tube from the capital of the still into a large copper recipient; by another tube this was joined to a second recipient through a series of four vessels arranged according to the plan proposed by Woulfe. The last vessel is then made to communicate with the worm of the first refrigerator, by which means the body of the still and the two recipients nearest to it are charged with the wine or fermented liquor, and, when ebullition takes place in the still, the vapour arising from it soon communicates the boiling temperature to the liquor in the two recipients; from these the volatilized alcohol will rise and pass into the third vessel, which is empty. After imparting a certain heat to it, a portion of the finer or less condensed spirit will pass into the fourth recipient, and thence in a little time into the worm of the refrigerator. The wine round the worm will also acquire heat, but more slowly; therefore the vapour, which in consequence may pass uncondensed into the first worm, is conducted into a second surrounded with cold water. Whenever the still is worked off, it is replenished by a stop-cock from the nearest recipient, which in its turn is filled from the second, and the second from the first worm tub; it is thus evident that, by keeping the third and fourth recipients at a certain temperature, alcohol may be formed of any degree of lightness at the remote extremity of the apparatus; by this means a great economy is effected in the expenditure of fuel, and the flavour of the spirit much improved. Several stills on this principle have been constructed at Glasgow for the West-India distillers; but the Excise laws do not permit their employment in the home trade.

Adam's principle of distillation.

It has been stated that the English distiller is not at liberty to avail himself of this form of still; the process of distillation in this Country is therefore conducted on a different principle to that above mentioned, and it will be proper before we proceed further to give some account of the English process. We may observe, generally, that all distilling vessels are either alembics or retorts; the former consists of an internal vessel called a curcubile, designed to contain the matter to be operated upon, and has an upper part fixed to it called the capital or head, in which last the vapours are condensed by its contact with the surrounding air, or by the assistance of cold water, enclosing the head in a vessel called the refrigerator or cooler. From the lower part of the capital or still-

Alembics described.

Manufac-
tures.

Retorts.

British
mode of dis-
tillation.
Wright's
Patent.
Pl. lxxxvii.
Fig. 1.

head a tube proceeds called the nose or beak, through which the vapours, after condensation, are made to flow into a vessel called the receiver, which is usually spherical.

Retorts are a kind of bottle formed in a small way of glass or earthenware, and in the large way of metal, the bottom part spherical and the upper part gradually diminishing into a neck which is turned on one side.

Various means have been had recourse to in applying heat in distillation, depending upon the nature of the apparatus employed as well as upon the substance to be distilled; but the common still, being formed of metal, is immediately exposed to the naked fire, since from its tenacity, and its property of conducting heat with facility, it is not liable to crack, which is not the case with glass or earthenware.

(1131.) The above general description will be better understood by referring to plate lxxxvii. fig. 1, which is the representation of a Patent still by Mr. Wright, engineer, in the Kent-road. The still is of metal, as usual; and has an internal division *a a*, which forms the still into two compartments; these are both filled with wash or other liquor intended for distillation. The still is heated by the furnace below, and the vapour from the lower compartment is driven through the tube *b*, and descends by the bent pipes *c, c* into the wash of the upper compartment; from the tube *b*, without the bent pipe, the vapour may be dispersed above the surface of the liquor within the still, by the intervention of a plate placed over the tube *b*, and a pipe *d* to the vessel of water, whence it descends again by the pipe *e* into the upper compartment of the still; by this means a partial condensation will have been effected of the grosser vapours which have arisen from the lower compartments, and the lighter or uncondensed vapour will pass off through the perpendicular pipe *f* to the condensing apparatus, where it finally becomes spirit. The heat of the furnace being continued, the vapour from the upper compartment of the still will also be driven off and pass through the pipe *f* to the condensing apparatus. A small pipe *g*, with a stop-cock, is inserted into the tube *b*, and carried through the vessel of water, by which a small quantity of the vapour from the lower part of the still may be admitted into the glass vessel *h*, for the purpose of ascertaining the quality of the vapour. When the spirit is out of the lower compartment of the still, and the upper compartment reduced to the gravity intended, the spent liquor below is to be drawn off through the cock *i*, after which the valve *k* may be opened to admit the liquor from the upper to the lower part of the still, and the succeeding charge is drawn from the cistern *l*, through the pipe *m*, to the upper part of the still. The condensing apparatus consists of two cisterns placed one within the other; the inner one *l*, which should be made with copper, is filled with wash, or other liquor intended for subsequent distillation, by means of the pipe and funnel *j*. This vessel should at least contain two charges for the upper compartment of the still; the outer vessel *n n* may be made of wood, and must be charged with water circumscribing the inner vessel; but when the former vessel is attached to other stills, the outer one *n n* may be dispensed with and the pipe *o o* attached, which must communicate with another condenser. The vapour passing from the still through the pipe *f*, as above described, proceeds to the spiral condensing pipe *p*, which passes several times round the vessel *l*, and, the vapour being cooled and condensed in

its progress, finally collects in the form of spirit and is drawn off through the pipe *o*; *q* is a pipe inserted into the head of the vessel *l*, with a light valve opening upward for admitting any vapour into the condenser *p* which might arise from *l*; but this, at the same time, prevents the passage of any vapour from the still through the pipe *f*; a water pipe *r* is attached to the cistern *n* to carry off the surplus water. The parts of this apparatus claimed as original are "a vessel to contain wash or other liquor in the progress of distillation, surrounded by a cavity for condensing the water from the still." The apparatus shown at *h* and *s* are glass vessels containing a number of graduated bubbles, of known gravity, for determining the specific gravity of the spirit.

Another improvement made by Sir Anthony Perrier, of the city of Cork, is to cause the liquid operated upon in the process of distillation to flow gradually over the heated surface of the boiler, whilst it continues to give out its spirituous evaporation. The quantity of liquid allowed to be acted upon, or to pass through the still in a given time, and also its velocity, is regulated by the circuitous route in which it proceeds, and by that means the complete operation of the fire upon the whole fluid is ensured without impeding or clogging the spirituous evaporation by aqueous or empyreumatic vapours. By this construction of a still, a continued and uninterrupted distillation, boiling, or evaporation is carried on so long as the supply of liquid is furnished and the fire kept up. Fig. 2 is a view in profile of the section of a still or boiler made on the improved principle, of copper, or of any other suitable material, and fig. 3 is a plan of the same. The bottom of this boiler is divided by concentric partitions, which stand up as shown in fig. 2, sufficiently high to prevent the liquor from boiling over; these partitions have openings from one to another at opposite sides, so as to make the course a sort of labyrinth; *a* is a reservoir of liquor prepared for the operation; *b* is a pipe or tube descending from the reservoir, and conducting the liquor to that part of the boiler marked *c*, which is the commencement of the race, from which the liquor flows through the channels, as shown by the arrows, fig. 3, progressively traversing the whole surface of the bottom, so that the full effect of the fire is exerted upon small portions of the liquid, which causes the evaporation to proceed with great rapidity. The residue of the liquor then passes off by the discharge pipe *d*, contrived to slide for the purpose of regulating the quantity and depth of the fluid intended for the still; and this pipe should be in such proportion to the admission pipe as to cause the perfect distillation of the liquor in its passage to the regulating tube. The spirit which rises in the head of this improved still will be found much stronger and purer than that obtained from stills of the ordinary construction, where the spirituous vapour is much mixed with aqueous matter and other impurities. The channels may be extended to any length required over a bottom of any dimension by contracting their breadth. Stills upon this principle may be made of all sizes and shapes, round, square, or otherwise; and the partitions may be placed in concentric or eccentric circles, with openings on their sides, at such distances as shall cause the liquor to flow over the most extended surface of the bottom; or, the still may be square, with angular partitions ranged as a labyrinth, or in any other manner, so as to cause the run of the liquor to be greatly extended over

Mechanical
Processes.

Fig. 2, 3.

Manufac-
tures.

the surface of the boiler. The bottom of these stills may be either flat, concave, convex, or of any other form, and the entrance of the liquor into the still, and also its discharging aperture, may be at the side, in the middle, or elsewhere, as circumstances may dictate. Boilers or evaporators may be made upon this plan either with or without heads, and their capacity of working may in all cases be increased by placing layers of pipes connected thereto within the flues, between the still and chimney, which pipes may be bent or coiled in a serpentine direction, or in any other position, and the liquor to be operated upon made to pass through them previous to its entering the still; thus the operation may be advanced to any required state of forwardness. Stills of the above description, particularly if made square, may be divided internally into several, each having its separate head and condenser, by which arrangement the spirit condensed from the first may fall into the second to be again operated upon, and so on to the third, whereby a rectification may be carried on to any degree at one operation and by one fire. In the still shown in fig. 2 a set of chains are seen suspended from the bar *ee*, supported by a centre shaft, that may be put in motion by a toothed wheel and pinion actuated by a crank or winch. These chains hang in loops, and fall into the spaces between the partitions, to sweep the bottom of the still as the shaft revolves; and thus they prevent the materials acted upon from burning when of a thick glutinous nature, as turpentine, syrups, &c.

It is impossible, of course, to describe the several forms which the still takes in the hands of different constructors, but the above will give a general idea of the process; other forms of British stills are described by Mr. Sheridan in his translation of Dubrunfaut, to which we have been indebted for the above.

Method of
distilling
rum in the
West
Indies.
Pl. lxxxvii.
Fig. 4.

(1132.) *Distillation of rum.*—The following description of an improved still constructed by Messrs. Shears and Son, as proposed by Mr. Corty, is given by Mr. Porter in his *Treatise on the Culture of the Sugar-cane*. The still is represented in plate lxxxvii. fig. 4, where A is the body of the still, B the still-head, which is made very capacious in order to guard against the accident of boiling over through mismanagement of the fire; C, C, C are discs, or plates of copper, placed very near to the tops of the boxes D, D, D, which have a supply of water on their upper surfaces, brought from the worm tub through the pipe E to the top of the upper box, and thence, through the pipes G, G, G, to the tops of the second and lower boxes, and, lastly, to the drain or sewer. The supply of water, escaping from the side opposite to that on which it enters, occasions it to flow over the whole surface of each box, which will thus be kept at nearly an equal temperature. When the wash is made to boil, the vapour, filling the head, strikes against the colder surface of the lowest disc C, and will at first be all condensed; but when the operation has been continued sufficiently long to heat the water contained in the lower box D beyond the boiling point of alcohol, the aqueous vapour alone will be there condensed, and the spirituous vapour will pass between the edges of the disc and the side of the box to the second box, and so on to the third, whence it passes, in a highly rectified state, to the worm of the condenser. When the still is fairly in operation, it is recommended to regulate the supply of water to the boxes by means of the cock F, so that in the upper box it may indicate the temperature of about 145° Fahrenheit, in the second box about 160°, and in the lower box

about 180°. The relative temperatures of the two lower boxes may be found to vary somewhat; but this is of no consequence, it being the heat of the water in the upper box that regulates the strength of the spirit by allowing more or less of aqueous vapour to pass over to the condenser. The temperature here mentioned of 145° is found, in the use of this apparatus, to condense so much of the aqueous vapour that the spirit passes on to the condenser nearly 50 per cent. over proof; but as it is found that rum of this strength does not possess its peculiar aromatic flavour in an equal degree with spirit of from 30 to 35 per cent. over proof, it will, perhaps, be thought desirable so far to depart from the instructions of the manufacturers as to allow the water in the upper rectifying box to acquire a higher temperature; these, however, are details which a very short experience will suffice to regulate. To the lower end of the worm a gas apparatus is affixed by a brass swivel joint screw H, the condensed spirit speedily fills the bent tube I, causing the separation of the carbonic acid gas which passes through the pipe K to the vessel L; this contains water at about two inches higher level than the bottom of the tube K; through this water the carbonic acid gas will escape preferably to passing through the bent tube L, where the resisting fluid column has a greater depth. The figures 1, 1 represent the solid masonry in which the still should be set; 2 is the fire-place; 3 the bottom plate which supports the mouth-piece; 4 the ash-pit; and 5, 5, side flues leading to the chimney.

Mechanical
Processes.

The specific gravity or strength of rum is commonly ascertained in our colonies by its capability of floating hollow bulbs of glass which are numbered according to their weight; but this method is by no means accurate, unless allowance is made for variations of atmospheric temperature, which materially affects the apparent strength of spirits. These bubbles are differently numbered, and when the thermometer stands at 70°

Specific
gravity of
spirits.

No. 17	indicates	41	per cent. over proof by the hy-
18	"	38	" [drometer.
20	"	27	"
21	"	24½	"
22	"	19½	"
23	"	16	"
24	"	11½	"
25	"	6⅞	"
26	"	½	"
27	"	5	under proof.

(1133.) It is much to be regretted that the duty on spirits has rendered it necessary to prescribe to the British distiller certain forms and processes to avoid impositions on the revenue, so that he has not been at liberty to avail himself so much as other persons of the advantages which Science has conferred on nearly all our manufactures. Amongst the many plans suggested for the improvement of distilleries, one of a very curious nature, which failed from the above cause, was proposed by Mr. Birch, of Roscrea, which was calculated to obviate the difficulty of procuring fuel, and to work the still much more advantageously by the application of steam than by the use of either turf or coals. In carrying on this experiment, the liquor in the still was boiled by the aid of steam raised in a boiler prepared for that purpose, and conveyed by a pipe which communicated with the exterior of the still only; but filling up with steam the spaces or interstices made in the formation of the still, and also the space between the still itself and

Distillation
by steam.

Manufac-
tures.

its case, which latter was made of wood, and every part of it exposed to view.

A trial on this apparatus was made before certain Commissioners of Excise at Roscrea. Previous to the trial there were four furnaces independent of the steam-engine, one for the still, and one for each copper, which contains two hundred and twelve superficial feet; but by the proposed plan these were reduced to two, containing only sixty-four superficial feet subject to the influence of the fire. It appeared, moreover, that steam not exceeding two hundred and twenty degrees was able to produce the highest charge of the Excise laws with a saving of four-fifths of the fuel, and the same of all other expenses. The plan, however, was rejected by the Excise on the principle that it would afford facilities to smuggling under the then existing regulations; but since the Act of the 4th of George IV. c. 94., has relieved the distiller from the production of a limited quantity in a given time, this steam method has been thought deserving of reconsideration.

These stills were made of copper: those capable of holding forty-four gallons were about forty-four inches in diameter at the bottom, and about five inches deep; those holding eighty gallons were fifty-four inches in diameter, and about eight inches deep; the bottom was perfectly flat, and about three-eighths of an inch thick; within it there were a number of iron chains turned round by machinery, which, by rubbing against the bottom, prevented the thick matter, which the wash always contains, from adhering to the bottom of the still and catching fire. This might have occasioned the immediate destruction of the still, and the scorched starchy matter would have communicated a disagreeable flavour to the spirits which could not have been got rid of afterwards; there was likewise a circular plate in the inside of the still towards its top, which broke the bubbles which arose during rapid distillation, and lessened the risk of the still boiling over, or *running foul*, as the distillers term it, consequently the distiller was enabled to put a greater charge of wash into the still than it would have been in his power to do had this circular plate been omitted.

The present stills, though much larger in size, imitate the others in the great diameter of their bottom. The top of the still ends in a kind of tube bent downwards, and connected with a tin tube which makes a number of revolutions in a large vessel filled with water, and therefore called the worm. This large vessel is called the *refrigerator* or cooler, and care is always taken to keep its situation in a state to do this by means of a stream of water constantly flowing into it. The wash being put into the still, and the top fixed down, heat is applied to the vessel till it is made to boil, when spirits, being more volatile than the water, go over first in the state of steam, and are condensed into a liquid as they pass through the worm. The first portions that come over are very strong, but the strength diminishes as the process proceeds: the distiller continues the operation till the liquid which flows from the worm is as heavy as water, or till the quantity of spirits remaining are not considered as a compensation for continuing the process any longer. The strength of the liquor proceeding from the worm is ascertained by a small hydrometer, with which it is tried every now and then, and whenever a certain mark on the instrument coincides with the surface of the liquid, a cock at the bottom of the still is opened, and what remains in the still is let off:

this is called the *spent wash*; it is a muddy brown liquid, and still retains a quantity of undecomposed saccharine matter which has been frequently used as food for cattle. To prevent the still boiling over, which is apt to take place towards the commencement of the distillation, it is usual to throw a piece of soap into the vessel along with the wash; the oily matter which the soap contains, being spread on the surface, forms a thin coat, which breaks the large bubbles when they rise, and thus prevents the wash from swelling beyond its usual bulk: butter would be less liable to communicate a disagreeable flavour, and so perhaps would hog's lard. It is impossible to lay down any rule with respect to the strength of the weak spirit obtained by this first distillation; it must depend partly upon the strength of the wort, and partly on the attenuation which has taken place during the fermentation, but chiefly upon the attention of the distiller to distil off the whole of the spirituous portion of the wash. The low wines are put into the still and subjected to a second distillation, which in Scotland is called *doubling*. The first portion which comes over is a milky liquid known by the name of *foreshot*; the third portion is called *feints*, which are mixed with what is called the low wines and distilled again. Another distilling apparatus is represented in fig. 5, the operation of which is sufficiently obvious without a verbal description. Mechanical Processes. Pl. lxxxvii. Fig. 5.

(1134.) TABLE, showing the Number of Gallons of British Spirits chargeable with the Excise Duty, from the Year 1820 to 1831, inclusive, with the Amount of Duty on the same.

Years.	Number of Gallons.	Amount of Duty.
1820	8,349,170	£3,941,879
1821	8,698,620	3,992,515
1822	8,754,291	4,275,381
1823	9,102,819	3,341,944
1824	15,107,849	3,894,725
1825	18,687,845	3,886,528
1826	18,233,400	*4,139,023
1827	19,684,678	4,172,233
1828	23,413,770	4,969,685
1829	22,690,270	4,783,950
1830	22,279,186	*5,185,574
1831	21,103,501	5,195,125

Method of making Crayons.

(1135.) Crayon is a general name for all coloured stones, earths, or other mineral substances, used by artists in designing or painting in pastel, and the same is still applied when these substances are first reduced to powder and re-formed for use. As considerable difficulty is experienced in obtaining good crayons, M. Lomes, a French artist of considerable note, undertook to make a variety of experiments with a view to obtaining them in the greatest perfection, an account of which is published in the *Annales de Chimie*. Red crayons are composed of the softer kind of ochre or reddle, which is an oxide of iron mixed with an argillaceous earth

* The reduction in the rates of duty on British spirit was, in 1823, from 6s. 2d. in Scotland, and 6s. 7d. in Ireland, to 2s. 4½d. per Imperial gallon; 1826, in England, from 10s. 6d. to 7s. per gallon.

Manufactures.

called hematites or bog-ore. This must be incorporated with some agglutinating substance, such as gum, glue, or rosin, to which is sometimes added soap for softening the composition; but instead of reddle other red oxides of iron, as colcothar of vitriol, &c. are used. These should be selected from those which are the softest to the touch, and of a lively colour, avoiding any mixture of clay, which produces a yellow tint. The ochre thus selected should be ground with pure water on a marble slab, as in preparing colours for painters, and moistened only with sufficient water to make the stone slide. For preparing a large quantity, the reddle must be pounded and sifted through a fine sieve, then diluted with a large quantity of water in a trough, where, after being well stirred, it should be left for a few minutes to settle, that the grosser particles may subside to the bottom. The water, strongly impregnated with the finer particles, must then be poured off and allowed to settle for twenty-four hours. When the clear water has been poured off, a fine sediment will be obtained, which must be again pounded and washed; and this process must be repeated till the whole is reduced to the utmost fineness. The gum, glue, or soap necessary for giving to the crayons a due degree of solidity must be separately dissolved, the solution carefully mixed with pounded ochre or reddle, and the water evaporated by exposure to the sun or to the heat of a gentle fire, taking care frequently to turn the paste till it has acquired a consistence somewhat harder than butter. The crayons are then to be formed in the moulds, which may be done two ways: first, by spreading out the paste on a board, in which grooves are cut rather broader at the top and round at bottom, and of any length, size, and depth, according to the proposed bulk of the crayons; or otherwise, which is the better method, by forcing the paste through a pipe or funnel of an orifice equal to the size of the crayon. The paste thus formed may be left to dry in a cool place under the shade, in order to prevent cracks, which a more rapid desiccation would produce. When the rods are dry they are to be cut into a proper length, and the edges should be taken off; after which they must receive the first cutting, in order to give them a blunt point. The last operation is that of scraping them, for the purpose of taking off the hard, outward coat formed on the surface in drying, and which would prevent their making any marks. It may be necessary to rub a small portion of oil into the grooves of the wood that the paste may not adhere too closely to the moulds. Gum arabic and isinglass are the two best substances for mixing with the powder. The gum and soap may be dissolved in cold water; but the isinglass must be cut in small pieces, put into hot water, and dissolved in *balneo mariæ*. These solutions should be well diluted with water that they may be made to pass through a hair sieve, in order to remove any foreign particles. As it is difficult to incorporate the paste with the isinglass, they must both be heated and mixed over a fire with a heat equal to that of boiling water: it is necessary to mix the paste before it is moulded. The best mode is to beat it with a pestle or mallet, and so pound it again for some time before it is to be put into the moulds. Soap is not required but for those crayons in which gum is used. The best means to prevent waste during the operation will be to fix by experiments the quantity of water and of ingredients which the pounded reddle and the solutions form before the mixtures are made. The following statement will serve this purpose. 1. Dry reddle, or red

oxide of iron, 1 ounce; gum arabic, dry, 18 grains: crayons thus made are very friable, but they may be used for large designs. 2. Reddle, &c. 1 ounce, gum 21 grains, will yield strong crayons, rather friable, but excellent for large drawings. 3. Reddle 1 ounce, gum 24 grains, or rather $25\frac{1}{2}$ grains, will give smooth and solid crayons, the best for common use. 4. Reddle 1 ounce, gum 27 grains, will produce soft firm crayons fit for drawings which require delicacy and precision. 5. Reddle 1 ounce, gum 30 grains, will yield very firm crayons fit for small drawings which are to be highly finished. 6. Reddle 1 ounce, gum 33 grains, will give very hard crayons which cannot be used without some force. This is the greatest quantity of gum that can be employed in their composition; with more they would be useless. 7. Reddle 1 ounce, gum 22 grains, white hard soap 30 grains. Crayons thus formed have a somewhat browner cast than the former. Their consistence is good, and they may be easily cut. When crayons have soap in their composition, all the strokes made by them have always a shining appearance, if the touches are repeated somewhat too strongly. These crayons perfectly resemble those of Desmarest. 8. Reddle 1 ounce, isinglass 36 grains, produce crayons of a brilliant colour and excellent for use. With less isinglass they become brittle, with more too hard.

Mechanical Processes.

(1136.) *Crayons for tracing on glass.*—This is an invention of Mr. Howlett for perspective drawings. The instrument consists of a plate of clear glass fixed in a frame, and set upright on a tripod stand so as to bring it on a level with the eye of the artist. From the top of the tripod projects horizontally a light frame with a hole at the end for the purpose of supporting in a vertical position a pin, at the top of which is a small perforation, through which the artist looks while he traces on the glass the objects seen through it. So far the instrument does not differ in any material respect from those usually employed for this purpose. But as glass is not capable of receiving the traces made by the pencil, it is necessary to cover the surface of the glass with some substance, at the same time as transparent as possible, and capable of being marked by a pencil. These conditions, however, have not hitherto been found to be reconcilable. The most transparent paper that can be made is not capable of allowing distant objects to be seen through it with sufficient distinctness, and glass itself, though unexceptionable with regard to transparency, will not retain traces from a black-lead pencil, or from any other of the materials usually employed in sketching. The way in which Mr. Howlett solves this problem is by the invention of crayons capable of bearing a fine point and of leaving traces on the surface of the glass. In the use, therefore, of this instrument, the objects are delineated with the crayon on the surface of the glass, and afterwards a piece of paper is laid over the drawing and is secured by its four corners to prevent it from slipping. The glass with the attached paper is then held up to the light, and the objects already drawn on the glass are traced on the paper with a common pencil. If the paper, instead of being laid on the drawing, is placed on the opposite surface of the glass, the copy will be made in a reversed position, and is thus immediately adapted to the use of the engraver; or the tracing on the glass may be transferred to paper, by laying the paper over the tracing and rubbing them together with an ivory-handled knife. If the tracing paper employed is thick or opaque, so that the lines on

Crayons for tracing on glass.

Manufac-
tures.

the glass are only seen indistinctly through it, a great degree of blackness may be given to them by dusting the surface of the glass over with dry lamp-black, and then rubbing it off with a soft camel-hair brush very lightly applied: the traces made by the crayon being somewhat adhesive, the lamp-black will be fixed on them by the action of the brush, while it is swept off from the rest of the surface. The crayons are made of three degrees of hardness to suit any climate, and are not acted on by water, either fresh or salt. Asphaltum and yellow bee's-wax, in equal proportions, are melted together, and then lamp-black, just sufficient to give it a colour, is stirred in. The mixture is then cast into sticks, and forms a crayon suitable for a temperate degree of heat; but for very hot weather, the hardest kind of heel-ball, lowered with a little tallow, answers admirably. The glass plate, previous to drawing on it, should be rubbed well with a leather, in order to force from it any moisture or dirt, and the artist, while making the drawing, should wear a finger-stall. It is sometimes difficult to bring the crayon to a fine point with a common penknife, for if the edge of this latter is set to the shape of a very fine wedge it will slip through the crayon, and, on the other hand, a blunt edge will break off the point before it has been cut sufficiently fine; but if the knife is set chisel-shaped, the oblique surface being applied next to the crayon, shavings of extreme tenuity may be taken off and a very fine point will be the result.

Manufacture of Steel Pens.

Steel pens.

(1137.) The extraordinary extent of this manufacture renders it necessary that we should say a few words on the subject, although there is nothing very remarkable to describe. The steel is rolled into very thin plates the usual thickness of these pens, in pieces about 4 inches broad and 3 feet long. These are then placed successively under a stamping press, such as we have described under button-making, and pieces of the proper form for the pens are cut out with great rapidity. The nib is then introduced into a gauged hole of the proper form to receive it; it is then pressed into the cylindrical form, and the slit and other openings in the pen formed in like manner: they are then cleaned, and ultimately tempered. The cleaning is performed in a very curious machine. This consists of a tin cylinder about 8 or 9 inches in diameter and 3 feet long, with a hole in the middle of its length for putting in and taking out the pens, which hole is covered by a lid. The cylinder is hung on joints at each end to cranks formed one on each of two axles. These are furnished with a fly-wheel, and one of them with a handle. As this latter is turned, therefore, the cylinder is thrown up and down, and backwards and forwards, each end and every part of course describing a circle, whereby the pens are rubbed one against another, and ultimately come out beautifully bright and clean. This operation is carried on for three or four hours; but many thousand pens are operated upon at the same time.

Quill pens
made by
machinery.

(1138.) *Making quill pens by machinery.*—Short quill pens are sold properly formed for writing, which are cut by machinery as follows. The top and bottom of the quill being cut off, the open piece is run upon a cylinder, on to which it slips easily, and, being placed in a machine, two cutting edges are run along it, one on each side, forming the quill into two semicylindrical

pieces. These are laid in grooves with the round part downwards, and a plane run over the upper side or edges to make them smooth. They are then cut into proper lengths, two or three being formed out of each length, that is, four or six out of each quill. Each piece is now brought to the nibbing machine, which is a kind of cutting press, and each is lastly finished off with a few touches by hand from a sharp penknife.

Mechanical
Processes.

Black-lead Pencils.

(1139.) The best pencils of this kind are made from a natural ore of plumbago obtained from Borrowdale, in Cumberland; but the more common sort from an artificial compound of plumbago dust and antimony. The lumps of pure plumbago, when scraped and freed from dirt, are of irregular form, varying generally in size between that of a walnut and an egg. These lumps are cut into slices of about the thickness of a shilling by a small circular saw, which is put in motion by the workman turning a winch and fly-wheel with one hand, while he applies the lump of ore with the other against a metal face set at a proper distance from the disc of the saw, so as to act as a gauge or stop for producing the proper thickness in the slice. The saw runs vertically, and the ore is applied below it, the workman gradually raising it against the saw till the piece is cut off, when it falls down slice upon slice on a table below, these being of different sizes, from one to two inches in length, and of variable breadths. One edge is now made quite straight, and the insertion of the lead into the pencil commences. First, however, it should be observed that pieces of cedar are cut by a fine circular saw into square prisms of the intended length of the pencil, or rather into such thickness that two of them together form a square, one of them thicker than the other, so as to admit the groove cut to receive the lead to be in one piece only, this groove being ploughed out by a proper gauge plane. The workman takes now one of the slices of plumbago brought to a straight edge, and dips this straight edge into glue, he then inserts it in the groove, and with a sharp instrument makes a cut on each side along the edge of the wood, when by a slight force it breaks off, leaving again a straight edge. This is now dipped again in glue, and inserted at the end of the last piece, and again cut off, till the length of the groove is filled with the lead. The whole upper surface is then smoothed, and the other piece of wood glued on; the pencil is then square and rather rough.

It is now taken to be made round, preparatory to which it is passed along a circular saw set to an exact gauge, and cut also to a certain length. In order to give it its cylindrical figure it is passed through a square hole in an iron or steel puppet of the exact size of the pencil, and forced along by the workman. On the other side of this puppet is the revolving apparatus which cuts the pencil round; it consists of two gauges, and a small plane iron revolving round an open centre. Beyond this is a cylindrical hole in a steel plate; as soon, therefore, as the first end of the pencil is cut round it is forced into this circular hole, and, before the workman has lost the means of pushing it forward at the end that is square, the cylindrical end is pushed through the circular hole, so as to enable him to seize it with a pair of wooden nippers; and it is thus pushed and drawn quite through, and comes out beautifully

Manufactures.

Pencils for pencil cases.

round and polished, the latter effect being produced by the hole being rather smaller than the pencil, whereby the wood is compressed and polished, as above stated.

(1140.) *Cutting leads for pencil cases.*—The pieces of lead for the pencil cases, the original Patent of Mr. Mordan, are cut from slices of plumbago, such as is described above, first into square prisms of proper dimensions for forming the cylindrical pieces, which are then made round by forcing them lengthwise through three different sized circular holes cut in pieces of ruby. In passing through the first hole only the four angles of the prism are taken off; it is then of course octagonal; the next hole, which is smaller, takes off these eight angles, and it then becomes a prism of sixteen sides, and in the next passage through the smaller hole it attains the true cylindrical figure.

The manner of forcing the lead through the several holes is not much unlike that in which the lead is forced up in the pencil case itself; that is, in a piece of metal about three inches long is a hole lengthwise, just big enough to receive the first prism, and at the other end of this is the ruby hole mentioned above. This piece of metal runs in a groove to preserve its direction, and the end of a steel pin, fixed in an upright piece of iron at the proper height, is introduced into the hole into which the lead is dropped, and a boy then presses the movable piece of metal containing the lead against the pin, which forces the piece forward through the ruby hole cutting off its angle as above described. A number being thus cut, he passes them all in the same way through the next, and lastly through the third hole, when they are ready for use.

Glue.

Glue manufacture.

(1141.) This is a substance used in various processes, as in making size, but more especially by joiners, carpenters, and other artisans; the consumption of which therefore is considerable, and some rather large establishments are appropriated to its manufacture. The English is reckoned the best, and is exported to other Countries. This substance is made of the skins of all kinds of beasts, oxen, calves, sheep, &c., or rather from fragments of them, as whole skins are too valuable to be thus employed except in very rare cases, that is, for glue of the best quality.

The materials above enumerated are first digested in lime water to cleanse them from grease or dirt; they are then steeped in clean water with frequent stirring, and afterwards laid in a heap and the water pressed out; they are then boiled in a large brass caldron with clean water, skimming off the dirt as it rises, and it is further cleansed by putting in, after the whole is dissolved, a little melted alum or lime finely powdered. The skimming is continued for some time, after which the mass is strained through baskets and suffered to settle, that the remaining impurities may subside; it is then poured gradually into the kettle again, and further evaporated by boiling and skimming till it becomes of a clear dark brownish colour. When it is thought to be strong enough, it is poured into frames or moulds about six feet long, one broad, and two deep, where it gradually hardens as it cools, and is cut out when cold by a spade into square cakes. Each of these is placed in a sort of wooden box, open in three divisions to the back; in this the glue, while it is still soft, is cut into three slices with a kind of bow, with a brass wire in the place of the string; now the slices are taken into the

open air and dried on a kind of coarse network, fastened in movable sheds four feet square, which are placed in rows in the glue-maker's field; having become perfectly dry and hard it is fit for sale. The best glue is that which swells considerably without melting by three or four days' immersion in cold water, and recovers its former dimensions and properties by drying. If the glue should be injured by frost, or look black and thick, it is necessary to melt it over again. The purchaser may easily detect bad glue by holding it before the light, for if good it will appear of a strong dark colour and free from cloudy and black spots. Carpenters commonly break the glue in small pieces and soak it four and twenty hours in cold water, and then melt the pieces, allow it to simmer very slowly over a fire, and keeping it frequently stirred; when done in this way it becomes, when cold, a firm jelly, which may be cut by any instrument. It only requires to be warmed to be fit for use, and in this state spread over the surface of the wood with a stiff brush; in two or three days the pieces of wood will be so perfectly cemented that boards thus joined will as readily break in any other part as at the junction. Glued boards will not set in a freezing temperature, the stiffening being occasioned by the evaporation of the superfluous matter of the glue, which is prevented by a considerable degree of cold.

The above is the usual kind of glue, and of which the largest quantities are employed; but there are other kinds of glue used for particular purposes which it will be proper to speak of in this place. Of these, fish glue is the most important, which is made of the skins and mucilaginous parts of fish. These, being boiled, bear a near resemblance to that viscid matter found on the skin of cod-fish. When boiled to the consistence of a jelly it is spread on a leaf of paper and formed into cakes, in which state it is fit for use. Fish glue is much used in medicine and many other Arts; but this is better known under the name of isinglass and ichthyocolla. A strong glue may be prepared with isinglass and spirits of wine, by steeping the isinglass for twenty-four hours in spirits of wine or common brandy. When the menstruum has opened and mollified the isinglass, they must be gently boiled together and kept stirring till they appear well mixed, and until a drop of it allowed to cool will soon turn to a strong jelly; it is now to be strained through a clean linen cloth into a vessel to be kept close stopped. A gentle heat suffices to dissolve this glue into a transparent and almost colourless fluid, but very strong, so that pieces of wood glued together with it will separate as easily any where as in the parts joined.

A strong compound glue may be made by infusing a mixture of common glue, in small pieces, with isinglass glue, in as much spirits of wine as will cover them, for about twenty-four hours; then melt the whole together, and as much powdered chalk is to be added as will make it an opaque white. By dissolving gum sandarac and mastic, of each two ounces, in a pint of spirits of wine, a strong glue may be obtained which will resist moisture; an ounce of clear turpentine must be added to the above mixture, equal parts of isinglass and parchment glue, pounded into small pieces; the solution of the gum is to be poured upon them, and the mixture melted in a covered vessel with a heat less than that of boiling water, then the glue, after being strained through a coarse linen cloth, is to be again placed over the fire, and an ounce more of powdered isinglass added to it.

Mechanical Processes.

Manufac-
tures.

Another strong glue that will resist water may be made by adding half a pound of common isinglass glue to two quarts of skimmed milk, and evaporating the mixture to a due consistence. A glue that will hold against fire and water may be made by mixing a handful of quicklime with four ounces of linseed oil, and boiling them to a good thickness, and spreading the mixture on tin plates in the shade; it will thus become extremely hard, but will easily be dissolved over a fire and be fit for use.

Sealing-wax.

Sealing-
wax.

(1142.) This well-known substance is a composition of gum lac melted and prepared with resins, and coloured with pigments of various hues, of which, however, the prevailing one is red. The hard red sealing-wax is made by mixing two parts of shell-lac, well powdered, and resin and vermilion, also reduced to a fine powder, of each one part; these are then melted together over a slow fire, and, when they appear thoroughly incorporated, formed into sticks in moulds ornamented or plain. Seed-lac may be substituted for the shell-lac, and instead of resin boiled Venice turpentine may be used. There is a coarser kind of hard sealing-wax, which may be made by mixing two parts of resin and of shell-lac, vermilion, and red lead, in the proportion of one part of vermilion to two of the red lead; the process of making this is like that of the former. The vermilion and shell-lac may both be omitted when cheapness is an object, but the wax thus made is of a very inferior kind. The best black, hard sealing-wax is prepared as above, except that the best ivory black is substituted for the vermilion, and in the coarser kind the common ivory black. Coloured sealing-waxes are prepared in other respects the same as the above, only altering the colouring matter, viz., for the green, instead of vermilion powdered verdigrise is employed; for a bright colour, distilled or crystals of verdigrise; for blue, powdered smalt, or for light blue, verditer or a mixture of both; for yellow substitute masticot, or for a bright colour turbith mineral instead of the vermilion. The hard purple wax is made like the red, only lessening the quantity of vermilion, and taking a larger or smaller proportion of smalt, according to the required shade of colour. The soft sealing-wax uncoloured is prepared by taking of bee's-wax one pound, turpentine three ounces, and of olive oil one ounce; they must be put in a proper vessel over the fire and allowed to boil for some time, when the wax will be in a proper state to form into rolls or cakes for use. To colour such soft wax, an ounce or more of any of the ingredients above mentioned must be stirred in while boiling till thoroughly incorporated with the wax. The hard sealing-wax is formed into sticks by rolling the mass on a copper plate or stone, with a rolling board lined with copper or block tin, into rolls of any required size. The polish or gloss is given to the sticks of wax by exposing them to a fire; for this purpose a furnace or stove is used resembling a pail, with bars at the bottom for holding the charcoal, and notched at the top of the sides for putting the wax over the fire; in this manner the sticks are conveniently turned about till the wax is so melted on the surface as to become smooth and shining. Hard sealing-wax may be formed into balls by putting a proper quantity on a plate, and, when made into a round form, it is to be rolled with the board till it becomes smooth. By pouring the soft wax into cold water it is easily formed

into rolls or cakes, and working it with both hands into any desired figure. These kinds of wax are sometimes perfumed; in which case to a pound of wax is added half an ounce of benjamin, one scruple of oil of rhodium, ten grains of musk, and of civet and ambergris each five grains, rubbing the oil with the other powdered ingredients, and, when the wax is in a fit state for working into sticks, the mixture must be sprinkled in and well stirred; or the same may be done by using one ounce of benjamin, one scruple and a half of oil of rhodium, and five grains of ambergris in the same manner.

Mechanical
Processes.

(1143.) *Wafer-making* for sealing letters are made by mixing fine flour with the white of eggs, isinglass, and a little yeast; this mixture is to be beaten into a paste; it is then thinned with gum water, and spread on even thin plates, dried in a stove, and cut for use. The different colours are given by tinging the paste with Brazil or vermilion for red; indigo or verditer, &c. for blue; saffron, turmeric, or gamboge for yellow, &c.

Wafers.

Starch-making.

(1144.) *Starch* is a substance employed in various processes in the Arts, and, although generally it is not made in quantities to require the application of large machinery, it is one which we think requires to be noticed in this place. Almost all kinds of seeds and the roots of most vegetables afford this substance in a greater or less degree; it is, however, obtained in greater abundance from wheat flour. This being moistened and made up into the form of dough or tough paste, and a gentle stream of water allowed to pass over or fall upon it, this will be found, when it leaves the paste, thick and turbid, which is occasioned by the starch or fecula which it extracts from the flour, and which subsides when the water is allowed to stand at rest. The substance thus obtained, when dried in the sun or by stove, is usually contracted into small masses of a long figure in the form of angular columns, which have a fine white colour, without smell and with very little taste; it is not soluble in cold water, but with boiling water it forms a thick paste, which, if allowed to cool, becomes semitransparent and gelatinous, and when dry is brittle, and somewhat resembling gum.

Starch,
nature of
described.

The process above described is too slow and expensive to be followed in manufacturing starch in large quantities. Here wheat, or such parts of it as are not used for food, is usually employed, such as the refuse wheat and bran; but when the finest starch is required, good grain must be used. This being well cleaned, and sometimes coarsely bruised, is put into wooden vessels full of water to ferment, and to assist the fermentation the vessels are exposed to the heat of the sun, and the water changed twice a-day during eight or twelve days, according to the season; the grain then bursts easily under the finger, and gives out a milky white liquor on being squeezed, when it is judged to be sufficiently softened and fermented. In this state the grains are taken out of the water in a sieve, and put into a canvass sack, the husks being separated and rubbed off by beating and rubbing the sack upon a plank; the sack is then put into a tub filled with cold water, and trodden or beaten till the water becomes milky and turbid from the starch which it takes up from the grain in this state. A scum swims upon the surface of the water; it must be carefully removed, and the water then run off

Mode of
manufac-
ture.

Manufac-
tures.

through a fine sieve into a settling vessel, where fresh water is poured upon the grain two or three times till it will not extract any more starch, or become coloured by the grain. The water in the settling vessels, being left at rest, precipitates the starch which it held suspended, and to get rid of the saccharine matter, which is also dissolved by the water, the vessels are exposed to the sun, which soon produces the acetous fermentation, and thus renders the starch more pure and white. During this process, the starch for sale in the shops receives its colour, which consists of smalt mixed with water and a small quantity of alum, which is thoroughly incorporated with the starch; but this starch is unfit for some other purposes. When the water becomes completely sour, it is poured gently off from the starch, which is washed several times afterwards with clean water, and at last is placed to drain upon linen cloths supported by hurdles, and the water drips through, leaving the starch upon the cloths, in which it is pressed or wrung to extract as much as possible of the water, and the remainder is evaporated by cutting the starch into pieces, which are laid up in airy places upon a floor of plaster, or of slightly burnt bricks, until it becomes completely dried from all moisture, partly by the effect of dry air and partly by the floor imbibing the moisture. In winter-time the heat of a stove must be employed to effect the drying; the pieces of dried starch are scraped to remove the outside crust, which makes inferior starch, and these pieces are broken into smaller pieces for sale. The grain which remains in the sack after the starch is extracted contains the husks and the glutinous part of the wheat, which are found very nutritious food for cattle.

French
method.

The French manufacturers, according to *Les Arts et Métiers*, pursue a more economical method, as they are enabled, by employing an acid water for the fermentation in the first instance, to use the most inferior wheat, and the bran or husks of wheat. This water they prepare by putting a pailful of warm water into a tub with about two pounds of leaven, such as bakers use to make their dough rise or ferment, the water stands two days and is then stirred up, and half a pailful of warm water added to it; then being left to settle till it is clear, it is poured off for use. To employ this water in the fermentation of the materials, a quantity of it is poured into a tub, and about as much fair water is poured upon it as will fill the tub half full. The remainder is then filled up with the materials, which are one half refuse wheat, and the other half bran. In this tub it continues to steep and ferment during ten days or less, according to the strength of the leaven water, and according to the disposition of the weather for fermentation. When the materials have been sufficiently steeped or fermented, an unctuous matter, which is the oil of the grain, will be seen swimming on the surface, having been thrown up by the fermentation; this being skimmed off, and the fermented grain taken out, is put into a fine hair sieve placed over a settling tub, when clear water is poured upon it and washed through the sieve into the tub, by which means the starch is carried through the sieve, with the water of which about six times the quantity of the grain is used. This water stands in the settling tub for a day, and becomes clear at top, when it is carefully laded out, leaving at the bottom a white sediment, which is the starch. The water thus taken off is called sure water; this is the proper leaven for the first steeping of the materials. The starch now ob-

VOL. VIII.

tained must be rendered marketable; for which purpose as much water is poured upon it as will enable it to be pounded and broken up with a shovel, and then the tub is filled up with clear water. Two days after this the water is laded out from the tub, and the starch appears at the bottom, but covered over with a dark-coloured and inferior kind of starch, which is taken off and employed for fattening hogs. The remainder of the sediment, which is good starch, is washed several times to remove all the inferior starch; and when this is done, about four inches of thick starch should be found at the bottom of each vessel, but the quantity varies according to the goodness of the meal or bran which has been used.

Mechanical
Processes.

It is evident that the refuse wheat when employed for making starch ought to afford more, the whole being used, than the bran or husks; but the starch so extracted is always of an inferior quality to that which is extracted from the bran of good wheat, particularly in the whiteness of its colour. In order to equalize the quality, the starch in the different vessels is mixed together in one, and there worked up with as much water as will dissolve the starch into a thin paste, which is put into a silk sieve and strained through with fresh water. This water is left to settle in a tub, and is afterwards poured off, but before it is so completely settled as to lose all its white colour; this renders the starch which is deposited still finer and whiter, and the starch which is deposited by the water so poured off is of a more common quality.

The starch thus purified is taken out of the bottom of the vessels and put into wicker baskets about eighteen inches long and ten deep, rounded at the corners, and lined with linen cloths which are not fastened to the baskets; the water drips from the starch through the cloths for a day, and the baskets are then carried up to apartments at the top of the house, where the floor is made of very clean white plaster, and the windows are thrown open to admit a current of air. Here the baskets are turned downwards upon the plaster floor, and the linen cloths not being fastened to the baskets follow the starch, and when taken off leave loaves or cakes, which are left to dry a little; these are then broken into smaller pieces, and left on the plaster floor till very dry; but if the weather be at all humid the starch is removed from the plaster floor and spread out upon shelves in an apartment which is warmed by a stove, and there it remains till perfectly dry. The pieces are afterwards scraped to remove the outside crust, which makes common starch, and the scraped pieces being again broken small, the starch is carried to the stove and spread out to a depth of three inches on hurdles covered with cloths. The starch must be turned over every morning and evening to prevent it from acquiring a greenish colour, which it would otherwise do.

(1145.) Potatoes are sometimes used for making starch by soaking them about an hour in water, and taking off their roots and fibres, then rubbing them quite clean with a strong brush, after which they are reduced to a pulp by grating them in water. This pulp is to be collected in a wooden vessel, and mixed up with a large quantity of clear water; at the same time another clean vessel must be provided, and a hair sieve, not too fine, must be supported over it. The pulp and water are thrown into the sieve, and the flour or starch is carried through with the water; fresh water must then be poured on till it runs through quite clear. The refuse pulp which remains in the sieve, being boiled in water,

Potato
starch.

Manufac-
tures.

makes an excellent food for animals; it is near seven-eighths of all the potatoes employed.

The liquor which has passed through the sieve is turbid, and of a darkish colour, from the extractive matter which is dissolved in it; but when it is allowed to rest for five or six hours all this matter deposits or settles to the bottom, and the liquor which remains is poured off as useless, and a large quantity of fresh water is thrown upon the flour and stirred up; it is then left to settle for a day, and, the water being poured off, the flour will be found to have again settled in a whiter state. But, to improve it, another quantity of water is poured on and mixed up with it, in which state it is passed through a fine silk sieve to arrest any small quantity of the pulp which may have escaped the first hair sieve. The whole must afterwards be suffered to stand quiet till the flour is entirely settled, and the water above become perfectly clear; but if the water has any sensible colour or taste, the flour must be washed again with fresh water, for it is absolutely necessary that none of the extractive matter be suffered to remain with it. The flour, when thus obtained pure and drained from the water, may be taken out of the tub with a wooden shovel, and placed upon wicker frames covered with paper, to be dried in some situation properly defended from dust.

Starch-mill. (1146.) When this manufacture is carried on in a large way, some kind of mill must be used to reduce the potatoes to a pulp, as the grating of them by hand is too tedious an operation. A mill invented by M. Baumé is very complete for this purpose. In its general structure it resembles a large coffee-mill. The grater consists of a cone of iron plate, about seven inches in diameter and eight inches in height, the exterior surface of which is made toothed like a rasp by piercing holes through the plate from the inside. This cone is fixed upon a vertical axle with a handle at the top to turn it by, and is mounted on the pivots of the axle within a hollow cylinder of plate iron, toothed withinside like the outside of the cone, the smallest end of the interior cone being uppermost, and the lower or larger end being as large as the interior diameter of the hollow cylinder. A conical hopper is fixed to the hollow cylinder round the top of it, into which the potatoes are thrown, and falling down into the space between the outside of the cone and the inside of the hollow cylinder, they are thus ground and reduced to a pulp when the interior cone is turned round by its handle, and as the lower part of the cone is fitted close to the interior diameter of the cylinder, the potatoes must be ground to a fine pulp before they can pass through between the two. The machine when at work is placed in a tub filled with water, and as fast as the grinding proceeds the pulp mixes regularly with the water ready for the process before described.

Mr. Whately's starch-mill.

A mill for the same purpose, on a different plan, has been proposed by Mr. Whately. This is a cylinder with its axis horizontal and turned by a handle at one end with a fly-wheel to regulate the motion; a hopper is placed over the cylinder into which the potatoes are thrown, and they are grated by resting upon the cylinder as it revolves round. There is also a horizontal box opposite to the cylinder into which the potatoes are received from the hopper through a sliding door; and a movable end, which is fitted to the box, is pressed forwards towards the cylinder by a lever and weight, so as to force the potatoes contained in the box against the cylinder, which being kept in constant motion grates

away the potatoes into a pulp with great rapidity, which falls into a box beneath.

In the year 1796, Lord William Murray obtained a Patent for manufacturing starch from horse-chestnuts. The method was to take the horse-chestnuts out of the outward green prickly husk, and either by hand with a knife, or tool, or otherwise with a mill adapted for the purpose, the brown rind was carefully removed, leaving the chestnuts perfectly white and without the smallest speck. In this state the nuts were rasped or ground to a pulp with water, and the pulp washed with water through a coarse horse-hair sieve, and twice afterwards through finer sieves, with a constant addition of clear cold water, till all the starch was washed clean from the pulp which remained in the sieve, and the water being settled deposited the starch, which was afterwards repeatedly washed, purified, and dried, in the same manner as the potato starch before described.

The sour, nauseous, milky liquor obtained in the process of starch-making appears, upon analysis, to contain acetous acid, ammonia, alcohol, gluten, and phosphate of lime. The office of the acid is to dissolve the gluten and phosphate of lime, and thus to separate them from the starch.

Another Patent has been obtained by Mr. Hill, the object of which is to deprive the starch of all its colouring matter, and to render it perfectly white by the action of the oxymuriatic acid. When the starch is ready for boxing, it is reduced with water to the consistence of cream. The oxymuriate of lime is then added to it and the whole continually agitated. A large quantity of water is next added, the mixture is well stirred, and the starch allowed to subside. The water is then drawn off, and dilute sulphuric acid poured upon the starch, and the whole agitated for some time. The starch is finally washed with repeated quantities of clear water, till all smell is removed from it.

Starch is used with smalt or stone blue to stiffen and clear linen; the powder of it is also used to whiten and powder the hair: the dyers also use it to dispose their stuff to take colours the better, and likewise for various other purposes.

The Amount of Duty paid on Starch manufactured in this Country from 1820 to 1831, inclusive.

Years.	lbs.	£.
1820	4,605,251	50,013
1821	4,658,141	54,198
1822	5,435,160	75,803
1823	5,739,894	70,680
1824	5,517,409	67,549
1825	6,621,782	74,554
1826	6,188,778	70,050
1827	4,357,969	85,239
1828	7,765,273	87,348
1829	6,367,207	66,699
1830	7,872,823	84,833
1831	7,557,336	78,805

Staining Paper.

(1147.) This is an important branch of the decorative Arts in this Country, and brings in some considerable amount in the form of revenue, every piece of paper thus employed being subject to a certain duty. There are three different kinds of paper, or rather three different ways of staining paper for hangings, viz. first, by printing

Mechanical
Processes.

Lord W.
Murray's
Patent.

Manufac-
tures.

Block-
staining.

on the colours; secondly, by what is called stencilling; and thirdly, by laying on the colours by pencil and brush; to which we may also add flock paper.

First method, with blocks.—When the colours are laid on by printing, the impression is made by wooden prints, which are cut in such a manner that the figure to be shown projects from the surface, by cutting away all other parts. This being charged with the colours tempered with their proper vehicle, by letting the print gently down on a block, on which the colour is previously spread, conveys it from thence to the ground of the paper, on which it is made to fall more forcibly by means of its weight, and the effort of the arm of the person who uses the print. The manner of performing this process may be more clearly understood by the following description. The paper, being properly prepared by a ground of whiting, colour, or varnish, is laid on a proper block, on which a piece of leather is stretched, and the colour, mixed with its proper vehicle, is spread on another piece of leather or oilcloth, laid on a flat block somewhat larger than the print, which is done by a boy or man who attends for that purpose, who, having the colour by him in a pot, spreads it with a brush on the block betwixt every stroke and impression the printer makes. The print is previously cut in such manner, correspondently to the design of the painting, that there shall be a projection on the surface answering to every part where that colour intended to be conveyed by this print is necessary; the workman takes the print and drops it gently on the block just charged with colour; from whence he again immediately raises it in the most perpendicular direction, and lets it fall with all his force on the paper, taking care to keep it perfectly even. This being done, the sheet printed is taken directly off the block and hung up to dry; and, another being put in its place, the same operation is repeated till the whole quantity is printed. It is easy to conclude that there must be as many separate prints as there are colours to be printed, and that they are to be used successively in the same manner as at first. But where there are more than one, great care must be taken after the first to let the print fall exactly in the same part of the paper as that which went before, otherwise the figure of the design would be brought into irregularity and confusion. In common paper of low price, it is usual, therefore, to print only the outlines, and lay on the rest of the colours by stencilling, which both saves the expense of cutting more prints, and can be practised by common workmen, not requiring the great care and dexterity necessary to the using of prints.

Printing by
the stencil.

(1148.) *Second method, by the stencil.*—This is effected as follows: the figure, with all the parts of any particular colour introduced into any proposed design, is cut out in a piece of oilcloth; this is called a stencil, and, being laid flat on the piece of paper to be stained, spread on a table or floor, is rubbed over with colour, properly mixed and tempered, by means of a large brush. The colour, passing over the whole, is of course spread on the paper where the cloth is cut away, and produces the same effect as in the block-staining above described. This practice, however, requires great care, particularly where there are small spots in the pattern, and where there are small continued lines running one into another; for in these cases it is difficult to preserve the connection or continuity of the parts of the oilcloth, or to keep the corners close down to the paper; for such patterns, therefore, blocks are preferable. Stencilling is, indeed,

a coarser and cheaper process, if done in an ordinary way; but to bring out as good effect as the block-staining requires so much care and skill, that the advantage of cheapness is lost; it is, therefore, we believe, seldom attempted except on bare walls, by which something like the effect of paper is produced, without incurring the expense of that material.

(1149.) *Third method, by the pencil.*—This being a slow process, and requiring the hand of an artist, is of course expensive, and is only had recourse to for the nicer sort of work; it is performed in the same manner as other paintings in water or varnish. In some cases it is employed only to fill the outlines already prepared by printing, where the price of the colour or the nicety of the design renders the block less proper for completing the process; sometimes it is used for forming or delineating some parts of the proposed figures, where a spirit of freedom and variety is required beyond what can be effected with the block.

In common pencil work, the method is first to stencil all parts of the colour in the design, and to give an outline to the whole at last with brown or black; but where there is any running parts, such as scrolls or stems or stalks of creeping plants or flowers, which are to be printed in any other colour than brown or black, a print must be used for them.

In the finer paper, where several colours are laid on with the prints, the principal colour is begun with, and the rest taken successively, the print for the outline being laid on last. In other cases, where the pencil is to be used, the outline is nevertheless to be made before the colours are laid on by the pencil, because, without this precaution, the figures would be likely to deviate too much from each other both in outline and position.

In paper printed with designs in chiaroscuro, such as the imitation of stucco-work and bas relievos, the order of printing must be to lay on the ground colour first, then the shades, and lastly the lights, and the same rule of succession must be observed where the colours are pencilled.

(1150.) *Flock paper.*—This is comparatively a late invention. The flock, which gives a great body and strength to paper thus coloured, is made from chopped cloth. The paper designed for this process is generally first prepared with a varnish ground of the proper colour, and it is not uncommon to print some small running figure in colours on the ground before the flock is laid on, which may be done with any pigment of the colour desired, tempered with varnish and laid on by a print or block cut for the purpose, the flock itself being afterwards laid on by a print or stencil. But as the latter can execute nothing but detached parts, and, consequently, is unfit for all designs where running work, scrolls, or other more complicated ornaments are introduced, it is extremely confined with respect to the nature of the designs for which it can be employed, and the print is therefore most generally preferred. The method of laying on the flock by means of a print is by having a print which is already cut in such a manner that the part of the design which is intended for the flock may project beyond the rest of the surface; the varnish is put on a block covered with leather or oilcloth, and the print is then used to lay the varnish on all the parts where the flock is to be fixed. The sheet, thus prepared by the varnished impression, is now to be removed to another block or table, and to be strewed over with flock, which is afterwards to be gently compressed by

Mechanical
Processes.

With the
pencil.

Flock
paper.

Manufac-
tures.

a board or some other flat body, to make the varnish take the better hold of it. Then the sheet is to be hung on a frame till the varnish is perfectly dry; at which time the superfluous part of the flock is to be brushed off by a soft camel-hair brush, and the proper flock will be found to adhere in a very strong manner. When the stencil is used, the same method is to be pursued, the varnish for holding the flock being laid on by that instead of a print, and the flock afterwards strewed upon it, as in the other case. The common manner of using the flock is by cutting woollen rags or pieces of cloth with the hand, by means of a large bill or chopping knife. But it is much more easily and better done by a machine, which may be worked by a horse-mill; at the same time such mill is employed for any other purpose, as grinding colours, &c. In such case, the construction of that part of the machine, which is made for the cutting the flock, is to take a box made for containing the rags or cloth to be cut, which is open at the top, and of such size as may best suit the quantity of rags that the force employed can cut. A blade is also to be made, the length of which is to be equal to the breadth of the box, and it should be strong, and must be charged with as great a weight as the force employed can be made to raise with a quick motion. The box, being filled with the rags or cloth to be cut, is placed under the blade, and made to move by hitches, after the stroke of the blade is given, just so far as where it is proper the blade should again cut the cloth or rags; while, at the same time, the blade is lifted up and let fall on the cloth, which it cuts through, till by successive strokes, and the progressive motion of the box under it, the whole quantity of cloth or rags in the box has been cut. The box must then be turned, so that one of the sides may become the front, and the operation must be repeated; by which means the cloth or rags, having been cut both ways, will be reduced to the state in which the matter is called flock, and fit to be employed for the purpose of paper-hanging. The work necessary for conveying from the principal mover in the mill the motion for thrusting forward the box and raising the blade may be easily supplied by any ingenious wheelwright, and need not, therefore, be particularly described here.

There is a kind of counterfeit flock paper which, when well managed, has very much the same effect to the eye as the real, though done with less expense. The manner of making this kind is by laying a ground of varnish on the paper, and having afterwards printed the design of the flock in varnish in the same manner as above; instead of the flock, some pigment or dry colour, of the same hue with the flock required by the design, but somewhat of a darker shade, being well powdered, is strewed upon the printed varnish and produces nearly the same appearance. *Handmaid of the Arts*, vol. ii. p. 458, &c.

Colours
used by
paper-stain-
ers.

The colours proper to be used for painting paper-hangings are all those that can be used in water and varnish; but for common designs done with water only the following are most proper: for red, lake vermillion, rose pink, and red ochre; for blue, Prussian blue, verditer, and indigo; for yellow, the yellow-berry wash, Dutch pink, and yellow ochre; for green, verdigrise, or a mixture of the blue colours with the yellow colours, particularly with the yellow-berry wash; for orange, vermillion or red lead, with Dutch pink; for purple, a wash made of logwood, or a mixture of the lake or rose

pink with deep-coloured Prussian blue, or with indigo; for black, ivory-black, and in some nicer cases lamp-black; for white, whiting; and for the heightnings, white lead; where great brightness is required, the lake should be used for the crimson red, and Prussian blue for the blue; but, for many purposes, rose pink used alone for the crimson red, and indigo mixed with whiting for the blue, will answer the purpose with much less expense. The lake, rose pink, Prussian blue, and Dutch pink, intended for this use, should be procured in a moist state. The colours used in varnish may be the same as those used in water; but for this purpose, those just mentioned should be obtained dry. As for the vehicles of the colours, when water is used, it must be inspissated with size and gum arabic or Senegal. When burnish is used, it must be formed of oil of turpentine, and the resins and gums which will dissolve in that menstruum. With respect to the grounds for paper-hanging, those that are laid in water are made by mixing whiting with the size above mentioned, and laying it on the paper with a proper brush in the most even manner. Nothing is more necessary when the ground is to be left white; and the paper being hung on a proper frame till it be dry is fit to be painted. When coloured grounds are wanted, the same method must be pursued, and the ground of whiting first laid, except that in paler colours a second coating may sometimes be spared by mixing some strong colour with the whiting. But where a greater force of colour is wanted, the pigment or colouring substance must be tempered with the proper vehicle, and then spread over the white coat. The varnish grounds are made much in the same manner, by mixing the proper colour with the varnish and spreading it on the paper.

(1151.) *Duty on stained paper.*—The stained-paper duty was imposed by the original Paper-Duties Act, (10 Anne, c. 18,) and is distinguished by its being a second charge upon an article already highly taxed in its plain or simple state. "Printed goods and stained paper" appear to have been officially classed together by the Board of Excise; and the Commissioners of Excise Inquiry observe, that it is remarkable the latter duty was not repealed at the same time with the former, to which it was much more analogous than to the paper duty.

The present duty on stained paper is 1½d. per square yard, averaging about 1s. per pound in addition to the 3d. per pound levied on the paper in its plain state. A drawback of the whole duty of 1½d. is allowed on exportation.

The amounts of stained paper charged with duty, and of revenue received therefrom, in the year ended 5th January, 1835, are as follows:

	Yards.	Revenue.
England	8,071,094	£58,851 14 6
Scotland	59,782	435 18 2
Ireland	618,268	4,508 4 1
	8,749,144	£63,795 16 9

There are 108 paper-stainers in England, two in Scotland, and forty-six in Ireland, each of whom is charged with a license duty of £4.

From the Excise regulations it appears that the stained-paper duty is charged on all paper prepared for use before it is stained; and that if a sheet therefore becomes spoiled or unsaleable in the staining, the paper-stainer must bear the loss.

The price of stained paper is stated to be 2s. 6d. per

Mechanical
Processes.

Manufac-
tures.

piece; the two duties amount to 1s. 3d., so that we have at once 100 per cent. of duty, in addition to incidental expenses, and to the losses of the nature above described.

The operation of this disproportionately high duty is very severely felt, particularly in the inferior papers, with regard to which Sir James Williams states, that "for 100 pieces of high-priced paper they sell 1000 of the low-priced." In such a state of things it is almost needless to add that evasion of duty takes place to a great extent, more especially in Ireland, where out of forty-six paper-stainers fourteen appear, from the Excise return for 1832, to have paid duty under £10, forty-three under £100, and three only paid duty above that amount. It is asserted that Irish stained paper is imported into England, and sells for one-third less than English paper, so that the evasion of duty in Ireland is not only injurious to the revenue, but prejudicial to the interests of the manufacturers of the United Kingdom.

Varnish Manufacture.

Various
uses of var-
nish.

(1152.) In the present advanced state of society in this Country, the decorations and elegances of life employ a great number of workmen in various Arts which were formerly almost unknown; and amongst these the manufacture of varnish may be included. The common bare walls of our ancient palaces were first hung with tapestry, then in less magnificent buildings stained paper, and now very commonly varnished painted walls are considered the most elegant finish to the architectural decoration of the finer rooms. The varnish for coach bodies used in this Country is also very considerable, as well as for various other decorations; so that the making of varnish, which was formerly merely the business of the artist who employed it, is now a distinct trade, and is carried on in many places on a considerable scale.

Apparatus
used in the
manufac-
ture.

Apparatus for varnish-makers.—In the *Transactions of the Society of Arts, &c*, vol. xlix., Mr. Neil, of King's Cross, Battle Bridge, has given a very particular description of the buildings and apparatus employed in this manufacture, and from this article we shall select such description as is consistent with our general plan.

The apparatuses employed are, 1. what is called the set pot, which is employed in boiling oil, gold size, japan, and Brunswick black; this is an iron vessel of the form of a common copper, about two feet deep, and two feet diameter, set in brickwork, having a spiral flue round it for about half its depth; 2. the boiling furnace; 3. the gum furnace; 4. the gum pot; 5. the boiling pot, copper ladles, sieves, &c. We do not consider it essential for our purpose to enter into a minute description of those parts which do not differ essentially from the usual form of such apparatus used in other similar processes, but, at the same time, any person wishing to carry forward such a process on a large scale may advantageously consult the Work to which we have referred.

Processes
described.

(1153.) *Process of varnish-making.*—As the least dust is exceedingly injurious to the varnish, it is important at the beginning of the operation that the making house be swept very clean. A quantity of oil, as for example eight gallons, is now placed in the boiling pot to be boiled, and in the gum pot is put first eight pounds of gum, when, the fire having been previously lighted, it will in a short time begin to give out steam and acid;

this must now be stirred and divided by the workman, and in about twenty minutes it will be found clear, resembling oil. During this time the oil is also so far heated as to simmer rather smartly; the boiling pot with the oil is now lifted off the fire, carried outside the building, and about one-sixth of the heated oil is poured into a copper vessel and emptied into the gum pot; the boiling is then continued until the oil and gum become concentrated and the mixture looks clear. Another sixth part of the oil is now added, and then again a third. These last operations are performed out of the first building, the gum pot having been removed for the purpose; there still remains about half the oil in the oil pot, and to this half the mixture of oil and gum in the gum pot is added; half a gallon of turpentine is then thrown into the empty gum pot, and with this and a *swish* it is well washed, and the contents emptied into a proper vessel; the pot is then wiped dry, placed again over its furnace with eight pounds more gum, which is proceeded with exactly as before, and then again with eight pounds more gum, when there will be in the boiling pot eight gallons of oil and twenty-four pounds of gum well incorporated; under this is kept up a brisk strong fire, till a scum or froth rises and covers the surface. It is now removed from the fire and taken to the place where the mixing was made, and well stirred, introducing the driers, and if the scum go down it is placed again over the fire; this process must be continued till the driers are all well incorporated; it is then mixed, when of a proper temperature, with about fifteen gallons of turpentine. In this state it is fit for use.

Mechanical
Processes.

(1154.) *Different Description of Materials for forming Varnishes.*

Gums copal.—Gums copal are of three different sorts and qualities; the best is brought from Sierra Leone; when imported, it is about the size of small potatoes, and is covered with a rough coat of dust or clay-like substance. It is most commonly bought in that state by varnish-makers, gum dealers, and druggists, who scrape it, that is, they generally have women who scrape it with sharp penknives or razors; it is indeed rather pared than cut quite free from dust; it is afterwards picked by hand into three different qualities. All the finest and palest is put by itself; this is called body gum; the next best is called carriage gum; from the remainder all pieces of wood, stones, &c., are taken away, and the remnant is made to serve for gold size or japan black.

Description
of materials
for varnish.

The second sort of gum copal, imported from South America, is, in appearance, somewhat like the African but much larger, and to those who are not good judges appears far the best, although in reality not worth one-third the value of the African; for after all the labour of scraping, picking, &c., it is in general so full of acid and sap, that not above two-thirds of it is fusible, and in many instances not more than one-third, and some whole casks are imported not worth any thing.

The third sort of gum copal is never imported by itself, but is found mixed among the gum animi; it is very large, pale, hard, and transparent, fuses and fixes well, and makes excellent varnish.

Gum animi is imported from the East Indies. It was formerly sold at the Company's sales in lots of two chests, each weighing from three to five hundred-weight, the sizes varying very much, as well as the quality.

Manufac-
tures.

The chests which contain the palest and largest gum always sell for the highest price, particularly those chests which are imported ready scraped; but there are great quantities imported which come over unscraped, being termed pickled, that is, cleaned from its dust by laying for several days in a very strong alkali well washed with a broom in water. This sort is not so good as that which is scraped with a knife; it is generally sold for one-third less than the former; but, in pickling and sorting animi, care must be taken to pick out all the fine, large, and transparent pieces: these are called body gum; the remainder is then picked and sorted.

Amber.—There are two kinds of amber, each of various qualities; the best is imported from Prussia and Poland; it is found in mines and rivers; it is very thin, solid, pale, hard, and transparent. Beads and other curiosities are made from this kind; it forms the most solid, hard, and durable varnish that can be made, either by employing it by itself, or as a component part with other gum. The other sort of amber is called sea-amber; it comes from many places abroad; its appearance is much darker than the first, and is about the size of coffee beans, more difficult to fuse, has less fluidity, affords more salt, gas, and acid during its fusion, and leaves a considerable quantity of impure earthy matter at the bottom of the pot on fusion, whereas the best kind will completely dissolve like oil.

Gum sandarach is so well known that no description is necessary.

Gum mastic may be procured at any druggist's shop, and is likewise well known. When very fine mastic varnish is required for valuable paintings, the mastic is put out upon a tea-tray or mahogany table, and every fine and clean piece picked out, until all the inferior, small, yellow, and dirty pieces are left; the fine is reserved for picture varnish, and the inferior for common mastic varnish.

Gum cat's eye is a large, pale, transparent gum, but little known; it is quite resinous and pulverulent between the teeth; it resembles gum sandarach; it is very pale, may be dissolved in hot turpentine, and is but little used except in making a varnish for paper-hanging, and adulterating common cheap mastic varnish; it is indeed very little better than pale rosin.

These are the principal gums required for making varnish; all others being in such small quantities, their description is unnecessary.

After having procured the necessary gums and sorted them, they are to be reduced to proper sizes for the gum pot, viz., to about the size of hazle-nuts, the larger pieces being broken by a proper hammer upon a thick sheet or plate of lead, in the course of which operation all black, dirty, or watery pieces are taken away to be mixed with other sorts of the same kind for common purposes.

Linseed oil is of peculiar consequence to the varnish-makers, as upon its quality in a great degree depends the beauty and durability of the varnish. Oil expressed from green, unripe seed always abounds with watery, pulpy, acidulous particles; the quality of oil may easily be determined by filling a phial with it, and holding it up to the light; if bad, it will appear opaque, turbid, and thick, its taste will be acid and bitter, and its smell rancid and strong; but the oil from fine, full-grown, ripe seed, when put to the same test, will appear limpid, pale, and brilliant, the taste will be mellow and

sweet, and it will have but little smell; it is specifically lighter than impure oil, and when clarified dries quickly and firmly; it does not materially change the colour of the varnish when made, but appears limpid and brilliant.

Essential oil, or spirits of turpentine, used for mixing varnish, ought to be chosen as pure, strong, and free from acid as possible. Turpentine which is drawn from green trees abounds with a pyroligneous acid which rises and comes over with the spirit in distillation; it is strong and bitter to the taste, and appears milky, particularly towards the bottom, after standing to settle.

Sugar of lead, when sought for the purpose of adding to varnish as a drier, ought to be that which has been made from white lead, instead of that from litharge, the former being the finest, and in its particles more pure and transparent. All sugar of lead contains about 14.2 per cent. of the water of crystallization, so that to use it in that state is very injurious to the varnish, as the water prevents that complete union of the particles of gum, oil, and lead, which ought to combine instantly and form a whole; therefore it is necessary to bruise the sugar of lead into powder, and lay it upon cartridge paper over a warm drying stove, where it should be frequently turned and moved about to prevent its running into a mass, until it gradually dries; it will then feel quite fine and soft, resembling hair powder; it should then be sifted through a forty-mesh sieve, which process renders it fit for the driers. It must be kept closed up in a dry stone jar until used, otherwise it will absorb moisture from the air.

White copperas, or sulphate of zinc.—The foreign article so called is chiefly imported from Germany; it is generally used as a drier for varnishes; in its undried state it is more objectionable than the sugar of lead, because it both discolours the varnish and injures the oil by affecting both its elasticity and durability. Another objection to its use in this state is that it requires the varnish to be kept for many months to settle, and if the varnish is not made very thin it does not get clear of the zinc at the bottom of the cistern; but when well dried it is the strongest and most effective drier, because it is entirely free from its watery particles.

Litharge is chosen as free from extraneous earthy matter as possible; that from the richest and softest lead is the best; this is called wind blow; it is in large broad flakes, appears very bright, and feels soft between the finger and thumb when rubbed; whereas the bad quality is known by an opaque, dull, or earthy appearance, and feels hard and gritty to the touch, and is very full of extraneous matter.

Red lead, like litharge, should be as free from earthy and extraneous matter as possible; when good, it will be found to be a strong and efficient drier.

Asphaltum.—There are many kinds of this substance, but the best is from Egypt; it is black, glossy, and heavy, and when rubbed upon a hot poker readily melts; it emits a very strong, disagreeable smell, like that of garlic or assafoetida, and cannot be dissolved in oil, water, or turpentine.

The next best quality is from Naples, which resembles the other in its appearance, but it is much more free from dirt, and may be dissolved in oil. There is a kind made in England which approaches in quality the best French, Naples, or German; this is the residuum

Mechanical
Processes.

Manufactures.

left from the burning of rosin, pitch, or linseed oil, which the makers of lamp-black burn for the purpose of condensing.

(1155.) *Composition of different varnishes.*—Eight pounds of the best African gum copal is to be fused; when completely in a fluid state two gallons of hot oil (old measure) are put to it; it is then to boil fifteen minutes; three gallons of turpentine taken from the top of a cistern is then to be added; but when the varnish is strained, if it is found too thick, more heated turpentine must be mixed with it.

Composition of different varnishes.

Artists' virgin copal.—The most transparent pieces must be chosen from a good sample of African gum copal; they are to be broken very small and dried before a gentle fire; after they become cool they are to be pounded into a coarse powder; then broken bottles or flint glass is to be boiled in soft water and soda, in order to cleanse it thoroughly, which is likewise to be pounded; the glass is to be dried in an oven; two pounds of it is now to be well mixed with three pounds of the pounded copal, and to be put into the gum pot to fuse; the glass will prevent the gum from adhering together, so that but little fire is required. When it is in a sufficient fluid state three quarts of clarified oil, very hot, should be poured to it; it must then be allowed to boil some time; five quarts of old turpentine is to be put in, and then to be immediately strained; it must be exposed to the air and light, but kept both from the sun and wet until of sufficient age for use.

Cabinet varnish.—Seven pounds of fine African gum copal is to be fused and added to half a gallon of pale clarified oil; in three or four minutes it is to be taken out of doors, then three gallons of oil mixed with it; it is then rendered fit for use.

Best body copal varnish for coachmakers, &c.—Two gallons of clarified oil is to be added to eight pounds of fine African gum copal fused; it must be boiled very slowly for four or five hours until quite stringy; three gallons and a half of turpentine are to be mixed with it; it is then to be strained and poured into a cistern. Varnishes made entirely from African copal possess more fluidity, pliability, and softness than those made from animi; the former keep the colour better, but the latter become darker after they are applied. Genuine copal varnish wears well; it never cracks, but, since it takes a long time to dry, coachmakers add to two pots of it

8 pounds of fine pale gum animi,
2 gallons of clarified oil,
3½ gallons of turpentine.

To be boiled four hours. This, after it is strained, is put hot into the two pots of varnish and well mixed together; this is done to cause the whole to dry quick and enable it to take a polish sooner.

Common Body Varnish for Coachmakers.

8 pounds of best African copal,
3 gallons of clarified oil,
3½ gallons of turpentine.

Boil four hours, or until stringy. When mixed, it will produce about five gallons and a half.

8 pounds of the best gum animi,
2 gallons of clarified oil,
3½ gallons of turpentine.

Boil as usual. To be mixed and strained hot, and put into the former pot of African gum varnish. Two pots of animi varnish is to be put to one of copal; this

mixture will dry quicker and harder than the best body copal, but will not wear so long. Mechanical Processes.

Quick drying Body Copal Varnish for Coaches.

8 pounds of the best African copal,
2 gallons of clarified oil,
¼ pound of dried sugar of lead,
3½ gallons of turpentine

Boiled till stringy, and mixed and strained.

8 pounds of fine gum animi,
2 gallons of clarified oil,
¼ pound of white copperas,
3½ gallons of turpentine.

Boil as before. Mixed and strained while hot in the first-mentioned pot. The mixture of these two ingredients will dry in six hours in winter and four in summer; it is principally used for varnishing old work on dark colours, &c.

Best Pale Carriage Varnish.

8 pounds second sorted African copal,
2½ gallons of clarified oil.

Boiled till very stringy.

¼ pound of dried copperas,
¼ pound of litharge,
5½ gallons of turpentine.

Strained, &c.

8 pounds of second sorted gum animi,
2 gallons of clarified oil,
¼ pound of dried sugar of lead,
¼ pound of litharge,
5½ gallons of turpentine.

To be mixed to the first while hot. This varnish requires the same time to dry as the last mentioned; it is used for all the purposes of coachmakers, house painters, &c.; its drying quality and strong gloss makes it very useful for general purposes.

Second Carriage Varnish.

8 pounds of second sort of gum animi,
2½ gallons of fine clarified oil,
5½ gallons of turpentine,
¼ pound of litharge,
¼ pound of dried sugar of lead,
¼ pound of dried copperas.

Boiled and mixed as before. When three runs are poured into the boiling pot, and the regular proportions added and well boiled, it will dry in half the time of the former varnishes; it is principally used for dark work.

Wainscot Varnish.

8 pounds of second sorted gum animi,
3 gallons of clarified oil,
¼ pound of litharge,
¼ pound of dried copperas,
¼ pound of dried sugar of lead,
5½ gallons of turpentine.

To be boiled until it becomes very stringy, and then mixed and strained. This varnish is likewise used for the same purposes as the above, and dries in the same time. Mahogany varnish is either made with the same proportions, or with a small portion of gold size.

Manufac-
tures.

Black
japan.

Black Japan.

This is made by putting into a set pot forty-eight pounds of Naples or any other of the foreign asphaltums, (except the Egyptian,) and as soon as it is melted pour in ten gallons of raw linseed oil. Keep a moderate fire, and fuse eight pounds of dark gum animi in the gum pot mixed with two gallons of hot oil and pour it into the set pot. Afterwards fuse ten pounds of dark or sea amber in a ten-gallon iron pot, keep stirring it while fusing, and whenever it appears to be over heated and rising too much, lift it from the fire for a few minutes. When it appears completely fused, pour in two gallons of hot oil, and empty it into the set pot; continue boiling it for three hours longer, and during that time introduce the proper quantity of driers, leave it to cool, and afterwards mix it with turpentine.

Water-proof Cloth.

Making
water-proof
cloth.

(1156.) Various attempts have been made to render cloth water-proof, and these have been attended with more or less success; but that which has supplanted nearly all others is a patented invention of Mr. Mackintosh, dated 1824, "for rendering fabrics of hemp, flax, cotton, wool, silk, and various other substances impervious to water." This is effected by the employment of a thick elastic varnish, made by dissolving caoutchouc in a small quantity of coal oil. The proportion of coal oil required to dissolve a given quantity of caoutchouc will vary according to its peculiar quality, as well as that of the resin; but the average quantity required will be about a quarter of a pint of the oil to a pound of resin. To facilitate the solution, the caoutchouc is to be cut into as thin shreds as possible, and the heat of a steam bath applied; when the solution is completed it is to be strained from the residuum.

To apply the varnish thus prepared, the cloth is to be stretched upon frames, and brushed over with it, and the varnished surfaces of two pieces of cloth, while in a sticky yet tolerably hard state, are laid one upon the other and passed between rollers subjected to pressure, which firmly and inseparably unites them. A flexible and thoroughly water-proof material is thus obtained applicable to a variety of useful purposes, without the inconvenient and unpleasant varnished sticky surface so common in other water-proof coverings.

This useful invention has found applications in various cases, but more particularly for large capes, cloaks, and for great coats, the former principally for walking in, the latter for riding, as they are found when close too warm for the former. This sort of cloth is also used for air cushions and beds, for water-hose and other purposes. A very ingenious application of this cloth was also made in some of our recent Voyages of Discovery, in which it was found necessary to have boats constructed very light for the convenience of taking them over land. In this instance the boat is made of wicker-work, with a casing of water-proof cloth; and by such boats very considerable rivers and pieces of water have been crossed. Another application was made of this substance by Mr. John Cow, of his Majesty's Dockyard, Woolwich, who contrived to form bandages of it for broken limbs. The usual bandages give frequently great pain when any swelling takes place, and they have sometimes to be relieved to the danger of displacing the bone; but by making the bandage of this material, and providing it with a pipe and stop-cock, the bandage, at first but slightly put on, may be blown up to any degree of pressure required, when, the stop-cock being turned, it will remain so; but on any occasion such as is spoken of above, the cock may be opened and the bandage slackened, and the pressure again restored without in any way disturbing the bandage.

Mechanical
Processes.

INDEX.

The Numbers refer to the Articles according to the Marginal Numbers of the Text.

Manufac- tures.

Acrospire, in malting, 1118.
Adhesion of wheels and rails, 302.
Air-vessels for regulating motion, 87.
Alarum for fire, clock, 446.
Alembics for distilling, 1130.
Alloys used in coining, 871.
——— casting cannon, 926.
Alum works, description of, 597.
Amonton's fire wheel, 150.
Annealing glass, 695.
Archimedes' screw, 340.
Arkwright's patent for spinning cotton, 978.
Authors on mills and mill-work, 122.
——— the steam-engine, 178.
——— the subject of hydraulics, 343.
——— clockwork, 913.

Balances of watches, 905.
Banca's proposition for the application of steam, 145.
Bands and straps for transmitting motion, 76.
Bark, quantity exported and imported, 462.
Barker's mill, 121.
Barometer gauges for steam-engines, 200.
Bayonet locking, for machinery, 51.
Beale's light for manufactories, 845.
Beaming in weaving, 1031.
Beaufoy's experiments on pendulums, 896.
Behnes's machines for sculpture, 1101.
Beighton's improvement of Newcomen's engine, 154.
Bellows for regulating motion, 87.
——— wooden, for forges, 384.
Bells, method of casting, 925.
Biscuit ware in the potteries, 660.
——— baking by the old process, 1114.
——— machinery, 1115.
Black's experiments and deductions of latent heat, 126.
Blake's investigation of the proper proportion of steam cylinders, 159.
Blakey's improvement of Savery's engine, 162.
Blast furnace in iron works, 562.
——— engine in iron works, 564.
Bleaching, sketch of the old method, 740.
——— modern system, 742.
Blending mill in pottery, 651.
Blinkinsop's locomotive engine, 302.
Block machinery at Portsmouth, 370.
Blocks used in paper-staining, 1147.
Blow-pipe in manufacturing glass articles, 701.
Blowing machines, 383.
——— in His Majesty's Dock-yard, Woolwich, Brun-
ton's, Sharp and Roberts's, 385.
——— glass, process described, 694.
Blue painting and printing in pottery, 665.
Bobbin-net manufacture, 1040.
Boilers for steam-engines, dimensions of, 182.
——— safety of, 184.
——— in locomotive engines, 317.
Bolting mill for flour, 497.
Bookbinders' and stationers' press, 429.
Boring machine for ship blocks, 372.
——— gun barrels, 941.
——— machines, various kinds, 386.
Bottle glass, manufacture of, 688.
——— jack, description of, 411.
Box, coupling, described, 46.
Brake for mills, 97.
Bramah's lock, description of, 414.
Brass, manufacture of, 594.
——— by cementation, 595.
Breaking machine, hemp manufacture, 1000.
——— worsted manufacture, 1023.

Brewing, 1125.
Brick-making, history of, 637.
Broaching engine, 379.
Broad glass, manufacture of, 687.
Brunton's locomotive engine, 302.
Bucket for water wheels, 111.
——— wheel, 340.
Buckets, chain of, 118.
Button-making, 862.

Cables, experiments on the strength of, 433.
Calender, description of, 389.
Calico-printing, 774.
Canal communication in Great Britain, 289.
Cap, self-adjusting, for windmills, 98.
Capstan, common ship, 393.
——— Phillips's, Smith's, and Eckhardt's, 393.
Card-making machine, Dyer's, 402.
Carding machine, cotton manufacture, description of, 989.
——— woollen manufacture, 1018.
Cartwright's steam-engine, 176.
Casting statues, 923.
——— bells, 925.
——— cannon, 926.
——— in plaster, 1100.
Cement, Parker's, composition of, &c., 463, 468.
——— mill for grinding, 465.
——— experiments on by M. Vicat, 470.
——— exposed to the action of water, 479.
——— Smeaton and Brunei's experiments on, 482.
Cementing furnace for the manufacture of steel, 575.
Centrifugal pump, description of, 350.
Chain of buckets, 118.
Chapman's locomotive, 302.
Charcoal, manufacture of, 600.
Chelsea waterworks, 857.
Clements's planing machine, 419.
Clock and watch making, history of, 879.
——— common, construction of, 885.
——— work, authors on, 913.
——— escapements, 897.
——— alarum for, 447.
Clothing the sails of windmills, 104.
Clutch, friction, for engaging and disengaging, 51.
Coal mines, history of, 230.
——— explosions in, 239.
Coals, probable time they may last, 232.
——— annual consumption of, 231.
——— method of working, 235.
——— unloading of, 6.
Cocoa-nut oil-mill, 512.
Cogged wheels, construction of, 37.
Coin, the wear of, 871.
——— of England, relative value of gold and silver, 872.
Coining, history of, 870.
——— process of, described, 873.
——— origin of the modern machinery, 875.
——— cutting-out mill, 877.
——— apparatus by Hague, 878.
Coke, making of, for iron manufacture, 561.
Coking engine, 377.
Colour mill, 483.
Combs and comb pot in worsted manufacture, 1026.
Comb-cutting engine, 321.
Combination or puzzle lock, 415.
Compensation balances for watches, 904.
——— pendulum, 887.
Condensation of steam, 144.
Condensing main in gas works, 827.
Conical friction rollers, 61.

Index.

Manufactures.

Conversion of motion, 71.
 Copper mining, history of, 211.
 — manufacture of, 585.
 — for porter brewery, 1127.
 Copying machine, description of, 401.
 Cords, rigidity of, 24.
 Corn and flour mill, Victualling-yard, Plymouth, 490.
 — and other grain imported and exported, 499.
 Corning house in gunpowder works, 719.
 Cornwall mines, annual production of, 212.
 — power of the pumping engines employed in the mines, 209.
 Cotton manufacture, history of, 970.
 — spinning by machinery, 974.
 — exported and imported, 982.
 — weaving, 983.
 Coulomb's experiment on the rigidity of cords, 24.
 Counting machines of different kinds, 403.
 Coupling-box, 46.
 Couplings for two bearings, 47.
 — by universal joint, 48.
 — by friction, 49.
 Cowl, a new form of, in malting, 1119.
 Crab for raising weights, 398.
 Cranes, common description of, 396.
 — method of working, by Wright, Hague, and Bramah, 397.
 Crank, the action of investigated, 73.
 Crayons, method of making, 1135.
 — for tracing on glass, 1136.
 Creighton's experiments on latent heat, 127.
 Crown glass, blowing of, 606.
 Crushing rollers in breweries, 1126.
 — oil-mills, 507.
 Currying leather, 793.
 Curvature of object glasses, 1105.
 Cutlery and hardware, 914.
 Cutting glass, process described, 696.
 Cylinders and pipes, action of, illustrated, 192.
 Dalton's formula expressing the relation between elasticity and temperature of steam, 137.
 Damper, self-acting, for steam-engine furnace, 187.
 Discharges in printing calicoes, 780.
 Disengaging machinery, 50.
 Dispersive instrument for opticians, 1105.
 — power of glass, 1105.
 Distilling, invention of, 1130.
 — apparatus by Woulfe, 1130.
 — by steam, 1133.
 Dividing mathematical instruments, 324.
 Donkin's counting machine, 407.
 Double-acting steam-engine, 204.
 Double cloth weaving, 1038.
 Doubling machine, silk manufacture, 1012.
 Draw-boy in weaving, 1035.
 — loom, French Patent, 1036.
 Drawing frame, cotton manufacture, 990.
 — machine in coining, 877.
 — frame, worsted manufacture, 1030.
 Dressing cloths, 1022.
 — frame, cotton manufacture, 986.
 — machines for flour, 498.
 Drilling engine, description of, 331.
 Drummond's light apparatus, 843.
 Duty of steam-engines, average of the, in Cornwall, 217.
 Dyeing, history of, 756.
 — theory of, 758.
 — materials exported and imported, 487.
 Dynamic unit, 2.
 Eckhardt's power capstan, 394.
 Efficiency of fuel in the production of steam and steam power, 142.
 Elasticity of steam, 131.
 Enamelling, in pottery, 668.
 — in glass manufacture, 712.
 — watch dial plates, 713.
 Engaging and disengaging machinery, 50.
 Engine, cutting, for combs, 321.
 — dividing, by Ross, 324.
 — for drilling metals, 331.
 — for cutting fibs, 332.
 — for cutting screws, 333.
 — for cutting original screws, 335.

Engine for cutting the teeth of wheels, 336.
 — for cutting keyways, 339.
 — pressure, for raising water, 341.
 — for cutting tobacco, 546.
 — blast, in iron works, 564.
 — fire, history of, 362.
 — modern fire, description of, 363.
 — local, for fires, 364.
 — for watering gardens, 366.
 — for drawing piles, 367.
 — coking, for ship blocks, 377.
 — broaching, block machinery, 379.
 Engines, locomotive, description of, 312.
 — application to common roads, 314.
 Engraving, different kinds of, 1086.
 Epreuves for ordnance, 434.
 Epsom salts, manufacture of, 619.
 Escapements of clocks, 897.
 — of watches, 907.
 Experiments on cements, lime, &c., 470.
 — on the elastic power of steam by order of the French Government, 135.
 — on the Liverpool and Manchester railway, 305.
 Explosions in coal mines, 239.
 Faraday's experiments on glass-making, 700.
 Fast and loose pulley, 50.
 Feeder, self-acting, for steam-engine furnaces, 186, 189.
 Files, engine for cutting, 232.
 Fire-engine, history of, 362.
 — escape by Davies, 365.
 Fishing-net manufacture, 1050.
 Flattening-mill, 934.
 Flax manufacture, 997.
 Flint glass, manufacture of, 693.
 — pan, in pottery, 650.
 Flock paper, 1150.
 Floor, temperature of a malting, 1119.
 Fly for regulating motion, 65.
 Fly-wheel and governor, 66.
 — theory of, 67.
 — construction of, 40.
 Forces, retarding, friction, 13.
 Forgery, means of preventing, 1092.
 Founding and foundry, 920.
 Framing of mill-work, 62.
 Friction, amount of, by different writers, 13.
 — Coulomb's theory of, 14.
 — Vince's experiments, 15.
 — Rennie's experiments and tables, 16.
 — of machines, 23.
 — wheels, 59.
 — rollers, patent, 60.
 — conical, 61.
 Fuel, quantity and efficiency of, 141.
 Fulling, in the woollen manufacture, 1021.
 — mill for cloths, 501.
 Furnace, blast, in iron works, 562.
 — refining and puddling, 570, 571.
 — residuum of, in iron works, 567.
 — for pipe-makers, 674.
 — in glass works, 691.
 — for enamelling, 714.
 Fusee of clocks, 883.
 Garden engine, description of, 366.
 Gas from oil, 836.
 Gas-meter described, 831.
 Gasometer, 823.
 Gas works, history of, 802.
 — first attempted, 810.
 — present process described, 822.
 Gauge cock for steam boilers, 188.
 — steam, 190.
 — barometer, for steam-engines, 200.
 Gensanne's form of steam-engine, 157.
 German snail for raising water, 340.
 Gig-mill in cloth manufacture, 1022.
 Gilding pottery and porcelain, 669.
 — buttons, 865.
 — general methods of, 935.
 Gin for raising weights, 399.

Index.

Manufactures.

Gland for engaging and disengaging machinery, 50.
 Glass works, history of, 675.
 — materials for making, 680.
 — for optical purposes, 681, 684, 699.
 — grinding and polishing, 703.
 — for refracting telescopes, 1106.
 — polishing, 704.
 — gull, 690.
 — furnace, 691.
 — cutting process described, 696.
 — works, at Ravenhead, 679.
 — method of colouring, 710.
 — and other buttons, 868.
 Glasses for watches, 693.
 Glazing, in calendering, 392.
 — in the potteries, 663.
 Glue, manufacture of, 1141.
 Gold-beating, 931.
 — wire, drawing, 933.
 Governor for regulating motion, 66, 70.
 Grant's biscuit-making machine, 1115.
 Granulating machine for gunpowder, 722.
 Gridiron pendulum, 890.
 Grinding in cutlery and hardware, 917.
 — needle, 957.
 Gudgeons, definitions, different kinds, &c. 52.
 — to solid iron shafts, 53.
 — hollow iron shafts, 54.
 — strength of, 55.
 — table of, for water wheels, 56.
 Gun founding, 926.
 — making, 937.
 — flints, manufacture of, 947.
 Gunpowder, manufacture of, 717.
 — different qualities, &c., 723.
 Gurney's locomotive carriage for common roads, 318.
 Hackling, in hemp manufacture, 1002.
 Hague's coining apparatus, 878.
 — method of working by means of a vacuum, 208.
 Hair-rope machine for raising water, 340.
 Hammer mills, 522.
 — riveting, block machinery, 378.
 Hand mill, 81.
 Hardware and cutlery, 914.
 Hat manufacture, 1059.
 Hemp and flax manufacture, 997.
 Hero's application of steam to produce motion, 145.
 High-pressure engine by Leupold, 155.
 — modern, 205.
 Hops, the revenue derived from, 1124.
 Horizontal windmill, 108.
 Hornblower's patent for steam-engine, 170.
 Horn press, 428.
 — buttons, manufacture of, 862.
 Horse and cattle mill, 93.
 — power, 2.
 — actual and nominal, 3.
 Hosiers, history of, 1046.
 Howard's vapour engine, 207.
 Hull's patent for steam boats, 156.
 Hydraulic engine, history of, 340.
 — ram for raising water, 342.
 — main in gas works, 826.
 — oil press, 510.
 Hydrostatic jack for lifting weights, 400.
 — packing press, 423.
 Jacks for raising weights, hydrostatic, hand, &c., 400.
 — for roasting, 408.
 — smoke, 409.
 Jenny spinning, cotton manufacture, 992.
 Jigger used in the potteries, 654.
 Inclined planes on railways, 299, 306.
 Indicator for steam-engines, 444.
 Indigo works, description of, 601.
 — culture of, 603.
 — mill, 484.
 Laking table, 1083.
 Iron mines, history of, 229.
 — railways, 292.
 — piling for wharfs, 309.

Index.

Iron works, description of, 605.
 — wharfs, construction of, 860.
 — wheels, construction of, 38.
 Kneading rollers in biscuit-making, 1115.
 Lace and bobbin-net manufacture, 1041.
 Lamp, thermo, by Le Bon, 813.
 Latent heat, 125.
 — Black's experiments and deductions, 126.
 — Watt's, Southern's, Rumford's, and Creighton's, 127.
 — Ure's experiments, 130.
 Lathe, original form, modern foot described, 412.
 — for facing ship blocks, 380.
 — for turning pins ditto, 381.
 Lead, manufacture of, 588.
 — mines, British, production of, 215.
 — pipes, casting and drawing, 927.
 — pencils, their manufacture, 1139.
 Leather, tanning, tawing, &c., 793.
 Lenses, proper curves for telescopes, 1105.
 Leupold's high-pressure steam-engine, 155.
 Leys, preparation of, in bleaching, 748.
 Lifting jack, jack in the box, &c., 400.
 Lighthouses, account of the English, 837.
 — revenue of, 839.
 — experiments on the most effective modes of lighting, 841.
 Lighting manufactories, 845.
 Lithographic printing, 1096.
 Liverpool and Manchester railway, 303.
 — experiments on, 305—308.
 — opening of, and accident to Mr. Huskisson, 309.
 — performance on, 311.
 Locks, various, description of, 414.
 — of guns, 945.
 Locomotive engines, first employment of, on railways and on roads, 293.
 — resistance of, on railways, 299.
 — description of, 312.
 — application to common roads, 314—316.
 — Parliamentary report on, 315.
 Logwood mill and preparation of, 485.
 Looking-glasses, silvering of, 450.
 Loom, common one described, 1032.
 — stocking weaving, 1047.
 — for fishing-nets, 1050.
 Machine, definition of, 1.
 — for planing wood, 416, 4
 — iron, 419.
 — for weighing, 457.
 — for proving iron cables, &c., 433.
 — for punching iron, &c., 438.
 — for ornamental punching, 441.
 — for registering, 443.
 — for silvering looking-glasses, 450.
 — for sowing, threshing, 452.
 — for drawing brass tubes, 455.
 — for reed-making, 457.
 — for biscuit-baking, 1115.
 — for dressing flour, 498.
 — drawing, in the Royal Mint, 877.
 — for forming ship blocks, 370.
 — for boring ship blocks, 372.
 — for mortising blocks, 373.
 — for shaping blocks, 374.
 — for scoring blocks, 375.
 Machinery, methods of engaging and disengaging, 50.
 Machines, miscellaneous, 370.
 — friction of, 23.
 — simple and compound, 319.
 — blowing, various kinds of, 385.
 — for boring cylinders, 386.
 — wooden pipes, 387.
 — stone pipes, 388.
 — for copying writing, 401.
 — for making cards, 402.
 — for counting, various kinds of, 403.
 Malt, revenue of, 1123.
 Malting, history of the malt duty, 1123.

Manufac-
tures.

Malting, theory of, 1117.
 Man hole in steam boilers, 191.
 Mangle, common, Baker's, &c., 389.
 Manufacture of iron described, 553.
 ——— comparison of materials employed, with the product, 559.
 Mashing-tun for porter brewers, 1128.
 Maudslay's vibrating steam-engine, 287.
 ——— engine for cutting the teeth of wheels, 337.
 Maximum effect of labour, 5.
 ——— overshot wheels, 114.
 Men, action and power of, at a windlass, 74.
 Mill-work, definition of, &c., 26.
 ——— framing of, 62.
 ——— for bolting flour, 497.
 ——— for bruising malt, grain, &c., 500.
 ——— for fulling cloths and flannels, 501.
 ——— for cutting out blanks in coining in the Mint, 877.
 ——— sizing and stamping, 877.
 ——— for flattening gold wire, 934.
 ——— blending, in pottery, 651.
 ——— for sugar-canes, 727, 728.
 ——— steel, for mines, 240.
 ——— stones, method of making, bedding, &c., 492.
 Mills, form and construction of, 80.
 ——— simple hand, 82.
 ——— tread, 83.
 ——— horse and cattle, 93.
 ——— wind, 94.
 ——— post, 95.
 ——— tower or smock, 96.
 ——— water, 110.
 ——— horizontal wind, 108.
 ——— and mill-work, authors on, 122.
 ——— of various description, 458.
 ——— bark, by Weldon, Chapman, &c., 459—461.
 ——— cement, for grinding. His Majesty's Dock-yard, Sheerness, 465.
 ——— for mixing mortar, pug-mill, &c., 466.
 ——— for grinding colours, indigo, &c., 483.
 ——— for cutting logwood, 485.
 ——— corn, flour, description of, 491.
 ——— for expressing oil, 504.
 ——— cocoa-nut oil, 512.
 ——— for rolling and forging, 514.
 ——— for working forge hammers, 522.
 ——— for sawing wood, 523.
 ——— marble, 538.
 ——— for the manufacture of snuff and tobacco, 545.
 Mines, copper, tin, lead, 211—215.
 ——— iron and coal, 223—230.
 ——— steam power employed in, 216.
 Mining processes in working for copper and tin, 223—225.
 Mixing machine in biscuit-baking, 1115.
 Mint, Royal, description of, 876.
 Modelling and casting busts, statues, &c., 1100.
 Mordants used in dyeing, 759.
 Morland's steam-engine, 148.
 Mortars, composition of, 475.
 Motion, regulators of, 63.
 ——— conversion and transmission of, 71.
 Motive and retarding forces, effect of on machines, 25.
 Movers, first, definition of, 2.
 ——— advantages and disadvantages, 12.
 ——— men, 4.
 ——— horses, 3.
 Mule spinning, 982, 996.
 Nail-making, 948.
 Needle-making, 954.
 ——— grinding, 957.
 Newcomen's original steam-engine, 154.
 New river, account of its formation, 854.
 ——— estimate of its work, 855.
 Oil, quantities imported and exported, 513.
 Oil-gas apparatus, 836.
 Oil-mill, common, and hydraulic oil press, 504, 510.
 Overshot water wheel, velocity of, 113.
 ——— maximum load of, 114.
 Paddle-wheels, action of, 274—281.
 Paper-making by hand, 1066.

Paper-making by machines, 1067.
 Paper-staining, 1147.
 Papin, claim to the invention of the steam-engine, 149, 152.
 Parallel motion for steam-engines, 201.
 Parkinson and Frodsham's pendulum, 889.
 Parliamentary investigation relative to steam navigation, 250.
 ——— report, 269.
 ——— on the application of locomotives to common roads, 315.
 ——— inquiry on the waterworks of the metropolis, 858.
 Paternoster work for raising water, 347.
 Payne's first scientific inquiry relative to the power of steam, 158.
 Pendulum for regulating motion, 64.
 ——— applied to clocks, 883.
 Pendulums of various kinds, 883—895.
 Penstocks for water-wheels, 119.
 Perrier's distilling apparatus, 1131.
 Phillips's power capstan, 393.
 Pile-engine, description of, 367.
 ——— proper height of, 368.
 Pin-making, 958.
 Pin-turning and polishing machine, 381.
 Pipes and cylinders in steam-engines, 192.
 Pipe-making furnace, 671.
 Piston, hemp-packed, 198.
 ——— metallic expanding, 199.
 Pix of the Mint, note, p. 610.
 Planing machine by Bentham, 416.
 ——— Bramah, 417.
 Plate glass, manufacture of, 685, 702.
 Plated manufacture, 959.
 ——— buttons and white metal buttons, 866.
 Platina, method of working, 593.
 Plumber blocks and steps, 58.
 Plunger pumps, 345.
 Polishing marble, how effected, 539.
 Pontifex's steam-engine, 163.
 Porter brewery, 1125.
 Post mill, 95.
 Potash, mode of obtaining, 610.
 Potter's contrivance for self-acting cock for steam-engine, 157.
 Pottery, different description of, 642.
 ——— processes and manipulation, 645.
 ——— handling, figuring, pressing, &c., 656.
 Power of steam-engines, 209.
 ——— aggregate, of steam-engines, 222.
 Power loom, invention of, 984.
 ——— description of, 1036.
 Press house in gunpowder works, 721.
 Presses, different kinds of, 421.
 ——— with differential screw, 422.
 ——— hydraulic, for packing, 423.
 ——— power gained, and strength required, 426.
 ——— for shaping horn, tortoiseshell, &c., 428.
 ——— for bookbinders and stationers, 429, 431.
 ——— for joiners, founders, &c., 432.
 Pressure engine for raising water, 341, 349.
 Printing, the history of, 1074.
 ——— press, common, 1078.
 ——— Stanhope's, 1079.
 ——— Ruthven's, 1080.
 ——— calicoes, &c., 774.
 ——— by resists, 779.
 ——— by discharges, 780.
 Propelling and resisting forces in steam vessels, 273.
 Proving machine, Royal Dock-yard, Woolwich, 433.
 ——— the strength of gunpowder, 435.
 ——— balls and shells, 436.
 Puddling furnace in iron works, 571.
 Pump, simple forcing and sucking, described, 346.
 ——— sucking, by Taylor, 351.
 ——— forcing, by Stephens, 352.
 ——— double piston, by Hedderwick, 353.
 ——— by Franklin, 354.
 Pumping and draining mines, 226.
 Pumps of various description, 344.
 ——— worked by cranks, 348.
 ——— centrifugal, described, 350.
 ——— for ships, by Smeaton, Noble, Kingston, Jekyl, 355—360.
 ——— chain, for ships, 361.
 ——— employed in mining, described, 227.
 Punching machine, 438.

Index.

Manufac-
tures.Purifier in gas works, 828.
Pyrometric beads, 661.Railways of wood, 291.
iron, 292.

Ram, hydraulic, 542.

Recoil, or barker's mill, 121.

Red lead, mode of manufacture, 607.

Reed-making machine, 456.

Reeling, in cotton manufacture, 996.

Refining furnace in iron works, 570.

Refractive power of glass, how determined, 1104.

Regulators of motion, 63. See Pendulum, Fly and Fly-wheel,
Venetian Fly, Air-Vessels, Bellows, &c.

Remedy of the Mint, 871.

Rennie's experiments on friction, 16, 17

Resistance on canals, 295.

on railways, 297.

law of, in steam-engines, 279.

Resisting and propelling forces in steam vessels, 273.

Resists in calico-printing, 779.

Retarding and motive forces on machines, 25.

Retorts for gas works, 825.

Rifle guns, 943.

Rigidity of cords, 24.

Roads, common, force of traction on, 294.

state of, in 1700, 288.

Roasting jack, common fly, 408.

bottle, described, 411.

iron ore, 560.

Roberts's engine for cutting the teeth of wheels, 338.

for cutting keyways, 339.

Robison's apparatus, 132.

Roller spinning, 993.

Rollers in the Mint, 876.

used in biscuit-baking, 1115.

crushing, in breweries, 1126.

Rolling-mill, 514.

process of, described, 516, 521.

Rope-making, 1052—1058.

Rum, method of producing, 1132.

Rumford's experiments for ascertaining the elastic power of steam,
129.

Ruthven's printing press, 1080.

Safety lamp, by Dr. Clanny, 241.

by Sir H. Davy, 242.

valve for steam-engines, 185.

Sails of windmills, construction of, 99.

Dutch ditto, 100.

clothing of, 94.

best shape and angle of, 101.

self-adjusting, 105.

Salt works and mines, 611.

application of steam to, 616.

Saltpetre, modes of obtaining, 620.

Salts, Epsom, manufacture of, 619.

Savery's Patent for a steam-engine, 151.

Sawing machinery in Portsmouth Dock-yard, 532.

Saw-mills, construction of, &c., 523—528.

Saws, circular, 529.

for veneers in Russia, 530.

used in the block machinery, 371.

trepanning, 376.

for cutting off piles under water, 536.

stone and marble, 537.

Screw-cutting engines, 333.

for original screws, 335.

Scribbling machine, woollen manufacture, 1007.

Sculpture, machine for, 1101.

Sealing-wax, manufacture of, 1142.

Self-adjusting cap for windmills, 98.

sails, 105.

Sewers, public, construction of, 850.

Shafts of coal mines, 235.

in mill-work, 42.

strength of, 43.

strain and twisting of, 45.

Shanks of buttons, various forms of, 867.

Shears for cutting iron and other metal, 449.

circular, in the Mint, 876.

Shearing cloth, woollen manufacture, 1024.

Shearing, machines for, 1025.

Ship pumps, by Smeaton, Noble, Kingston, Jekyl, 355—360.

Shot manufacture, 961.

Silk manufacture, 1005.

worm, management of, produce of, &c., 1006.

winding, doubling, tramming, &c., 1009.

Silver, reduction of the ore of, 590.

Silvering looking-glasses, glass globes, &c., 450.

Single-acting steam-engine, 192—203.

Sizing mill, in coining, 877, 878.

Slip kiln, in pottery, 647.

Slubbing billy, woollen manufacture, 1020.

Smeaton's experiments on cements, 480.

improvements on the steam-engine, 160.

table of the action of mill sails, 101.

remarks on ditto, 102.

Smelting copper, process of, 585.

ores of tin, 587.

Snuff and tobacco, manufacture of, 541.

Soap works, description of, 622.

Southern's experiments on latent heat, 127.

Southwark waterworks, report on, 859.

Sowing and threshing machines, 452.

Specula for reflecting telescopes, 1108.

machines for grinding and polishing, 1110.

Spinning jenny, invention of, 979.

Spiral pump for raising water, 340.

Staining paper, different processes, 1148, 1149.

Stamping mill in coining, 877, 878.

hammer for plated goods, 960.

Stanhope's printing press, 1079.

Starch, manufacture of, 1144.

from potatoes, 1145.

mill, 1146.

Steam, as a first mover, 10.

engine, its application to mining, navigation, &c., 123.

history of, 145.

list of authors on, 178.

modern description of, 179.

double-acting, 204.

vibrating, 206.

high-pressure, 205.

power of, 209.

duty of, defined, 217.

indicator, 444.

latent heat of, 125.

elastic power of, at high temperature, 134.

density of, at different temperatures, 138.

in contact with water, 139.

elasticity of, by different authors, 137.

not in contact with water, 139.

velocity of, into a vacuum, 140.

working expansively, 142, 172.

condensation of, 144.

boats, Hull's invention, 156.

navigation, history of, 243.

power on railways, 301.

vessels in America, 246.

parliamentary inquiry relative to, 250.

number of, in Great Britain, experiments on, 271.

proportions and dimensions of several, 285.

Steel manufacture, 574.

different kinds of, 577, 578.

tempering of, 579.

alloys of, 583.

pens, their manufacture, 1137.

Stencils used in paper-staining, 1148.

Steps and plumber blocks, 58.

Stereotype founding, 930.

Stocking frame, common, description of, 1047.

for ribbed stockings, 1048.

Strength of teeth of wheels, 34.

wheels, 41.

gudgeons, 55.

Striking part of a clock, 886, 903.

Sugar manufacture, 725.

culture of, 726.

mills, description of, 727—729.

refining of, 733—736.

quantities imported, 737.

of lead, manufacture of, 609.

Sulphate of zinc, manufacture of, 628.

Index.

Manufactures.

Sulphate of copper, 629.
 — of iron, 630.
 Sulphur works, description of, 625.
 Sulphuric acid, manufacture of, 627.
 Sun and planet wheel, 75.
 Table of the force of men and horses, 11.
 Tabulated elasticity of steam by different authors, 131.
 Tambour work, 1051.
 Tanning leather, 782.
 Tawing leather, 793.
 Teeth of wheels, construction of, 27, *et seq.*
 — engine for cutting, 336.
 — of bevelled wheels, 33.
 — strength and pitch of, 34, 35.
 Tell-tale for watchmen, 445.
 Thermo lamp by Le Bon, 813.
 Threshing machine, 452.
 Throstle spinning, 994.
 Throwing, in porcelain and pottery, 653.
 — mill, silk manufacture, 1005—1011.
 Tide gauge, by Palmer, 448.
 — mills, description of, 120.
 Tin mining, history of, 211.
 — manufacture of, 587.
 Tinning, method of, 952.
 Tobacco and snuff, manufacture of, 541.
 — quantity imported, exported, duty, &c., 543.
 Tower mills, 96.
 Traction, amount of, on common roads, 294.
 Transmission of motion, 71.
 Tread-mill, description of, 83.
 — method of conducting the work of in prisons, 85.
 — regulating velocity of, 86.
 — efficiency as a mechanical agent, 89.
 — advantages of for prison discipline, 90.
 — maximum and minimum of labour on, 91.
 — work performed on, in various prisons, 92.
 — labour on, 5.
 Trepanning saws, 376.
 Trevethick's locomotive, 302.
 Troughs for water-mills, 119.
 Tube-drawing machine, 455.
 Turning, in porcelain and pottery, 655.
 Type founding, 929.
 Valve, safety, in steam boilers, 185.
 Valves, the manner of working, 194.
 Vapour engine, by Howard, 207.
 Varnish, manufacture of, 1152.
 Velocity of steam into a vacuum, 140.
 Velvet, finishing of, 1039.
 Veneer, method of cutting, 530.
 Venetian fly for regulating motion, 86.
 Ventilating manufactories, 847.
 Ventilation of coal mines, 236.
 Viameter for measuring distances, 404.
 Vibrating steam-engine, 206.
 — cylinder applied to a steam vessel, 286.
 Vinegar, manufacture of, 631.
 — works, 631.
 Vitriol works, description of, 627—630.
 Under-shot water wheels, construction of, 115.

Under-shot water wheels, effect of, 116.
 Universal joint for coupling, 48.
 Ure's experiments on latent heat, 130.
 — apparatus for ascertaining the elastic power of steam, 133.

Index.

Warming manufactories, 845—848.
 Warping mill, 1031.
 Watch glasses, method of forming, 698.
 — dial enamelling, 713—716.
 Watches, construction of, 902.
 Water, as a first mover, 8.
 — wheel, buckets of, 111.
 — over-shot, velocity of, 113.
 — under-shot, construction of, 115.
 — quantity raised by the Cornwall steam-engines, 220.
 — works, history of, 852.
 — proposed improvement in, 857.
 — proof cloth, manufacture of, 1156.
 — cements, composition of, 479.
 Watt's remarks on the latent heat of steam, 125.
 — improvement in steam-engine, 164, *et seq.*
 — double-acting engine, 174.
 Weaving, 1030.
 Weaving, different kinds of, 1030—1034.
 Weighing machines, 457.
 Whale oil, processes employed in obtaining, 632.
 Wharfs, construction of, 860.
 — Patent cement, 861.
 Wheel carriage counting machine, or viameter, 404.
 Wheels, balance, over-shot, under-shot, breast, 8.
 — comparative power of, 9.
 — teeth of, 27.
 — strength of, 34.
 — bevelled teeth of, 33.
 — cogged, construction of, 37.
 — iron, construction of, 38.
 — hanging of, 39.
 — strength of, 41.
 — friction, 59.
 White lead, mode of manufacture, 608.
 Wind, as a first mover, 7.
 — mills, construction of, 94.
 — sails of, &c., 99, *et seq.*
 Windlass, description of, 395.
 — action of men at, 74.
 Wiredrawing, gold, 933.
 — common method, 966.
 — quantity used in a day at Dyer's card-making manufactory, 402.
 Wooden pendulums, 896.
 — railways, 291.
 Wool mill, or devil, 1017.
 — combing by hand, 1027.
 — by machinery, 1028.
 Woollen and worsted manufactures, history of, 1014.
 Wootz, or Indian steel, 581.
 Worcester, Marquis of, project of a steam-engine, 146.
 Worsted manufacture, 1026.
 Woulfe's steam-engine, 177.
 Wright's Patent distilling apparatus, 1131.
 Zinc, manufacture of, 592.

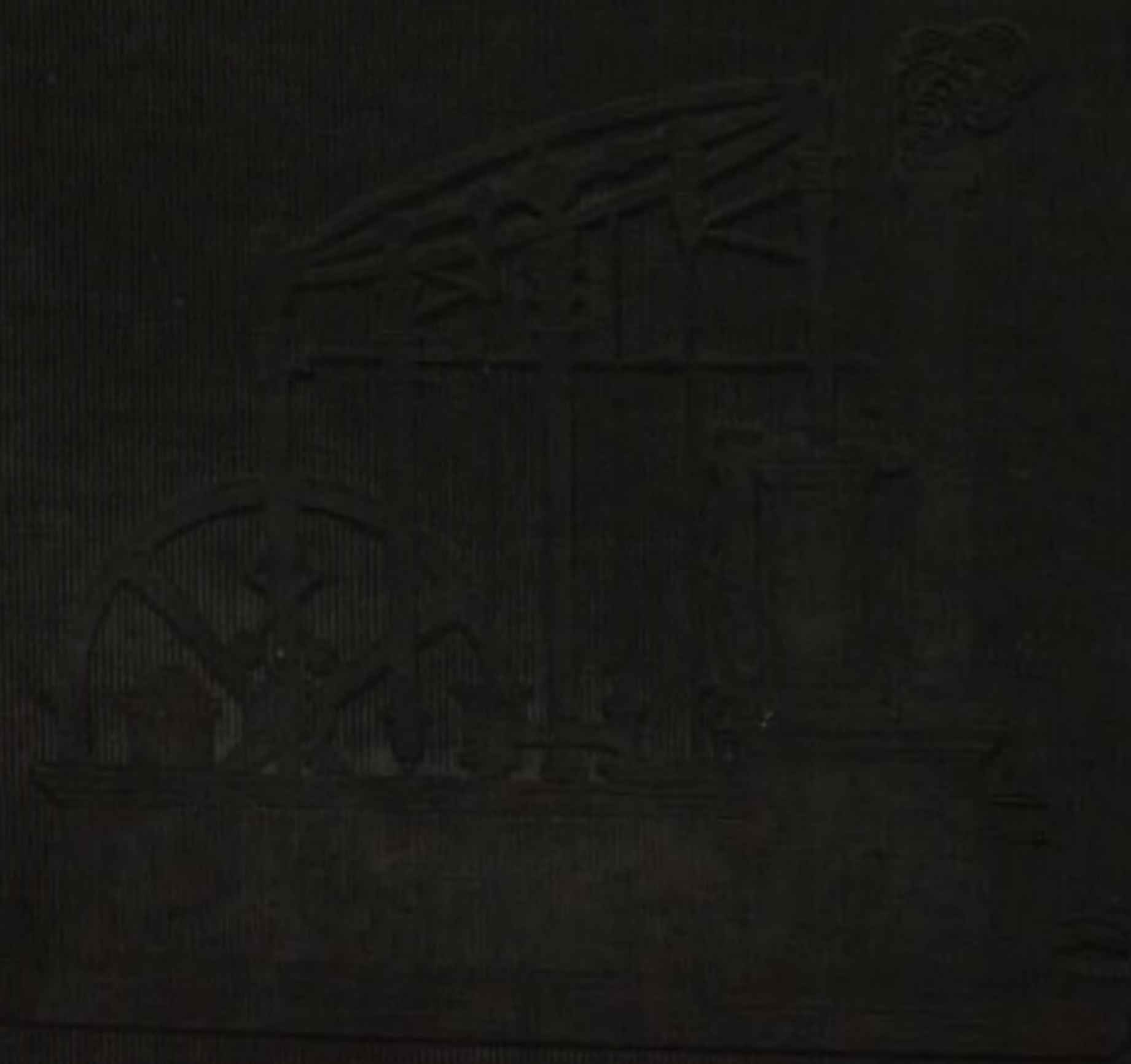
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